

# Postural Characteristics of Diabetic Neuropathy

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**OBJECTIVE** — To explore the posturographic correlates of diabetic neuropathy by comparing the performances of three groups of diabetic patients (severe, moderate, and absent neuropathy) with those of normal subjects and four clinical control groups.

**RESEARCH DESIGN AND METHODS** — Using the Interactive Balance System (Tetrax, Ramat Gan, Israel), based on the assessment of the interaction of vertical pressure fluctuations on four independent platforms, one for each heel and toe part, respectively, posturographic examinations were given to 28 diabetic patients (8 with severe, 12 with moderate, and 8 with no peripheral neuropathy), 30 normal control subjects, and a clinical control group of 52 patients (14 with stage II Parkinson's disease, 13 with brain damage, 7 with whiplash, and 19 with peripheral vestibular pathology). The following posturographic parameters were evaluated: 1) general stability; 2) Fourier analysis showing patterns of sway intensity within eight frequency bands between 0.1 and 3 Hz; 3) weight distribution; 4) synchronization of sway; and 5) performance patterns for eight positions, requiring closure of eyes and standing on an elastic surface, as well as left, right, back, and downward head turns.

**RESULTS** — For positions with closed eyes, diabetic patients with severe and moderate neuropathy were significantly less stable than normal subjects and diabetic patients without neuropathy, but diabetic patients with severe and moderate neuropathy turned out to be as equally unstable as clinical control subjects. However, for sway intensity within the band of 0.5 to 1.00 Hz on positions with lateral head turn with occluded vision, neuropathic diabetic patients performed significantly worse than did both normal and clinical control subjects. The same posturographic parameter also differed significantly between normal subjects and diabetic patients without neuropathy.

**CONCLUSIONS** — As reported in previous studies, general instability in diabetic neuropathy is not a sufficiently characteristic correlate of the syndrome. On the other hand, spectral analysis of sway on stressful positions involving head turning appears to differentiate diabetic neuropathy from other disorders involving postural disturbances.

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It is a well-established fact that proprioceptive information from the lower extremities is one of the main input sources (besides the visual and labyrinthine senses) that ensure and regulate postural control. As diabetic neuropathy is intimately linked with considerable restriction in this sensory modality, disturbances of postural control are a frequent, clinically

well-known symptom of the diabetic patient, actually labeled by some authors as "sensory ataxia" (1). In spite of this clinical evidence and the subjective complaints by many diabetic patients of feeling dizzy and unstable (1), an objective assessment of this problem by modern posturography has been reported only very recently in one U.S. (2) and two Italian papers (3,4).

The general design of these three studies is similar. A group of diabetic patients, subdivided into two subgroups with present versus absent neuropathy, is compared to age-matched normal subjects on posturographic measures of general stability. In all three studies, the same posturographic methodology is employed. This methodology is based on the assessment of a central measure of postural sway, which is expressed by the excursions of the path produced by the oscillations of the point of gravity being projected onto the area of support. This path is graphically plotted in the form of a crisscrossed blot that can be statistically evaluated by calculating 1) the surface of the area covered by the blot, 2) the length of the crisscrossed path, and 3) the velocity of sway obtained by dividing the length of this path by the time of performance. In the most recent Italian study (3), two derivative posturographic measures were added, namely the velocity of anteroposterior sway as a function of the forward shift of the point of gravity and the Fourier transformations of the lateral and anteroposterior oscillations. In all studies, two positions were tested: head straight with eyes open and head straight with eyes closed (classical Romberg test). In the U.S. study (2), two more difficult positions were added, supposed to induce labyrinthine stress: head back with eyes open and head back with eyes closed.

Results showed unanimously that the neuropathic diabetic patients, as compared with both nonneuropathic diabetic patients and normal subjects, were significantly less stable on the central postural measures (2–4). Similar results were obtained on the derivative score of the velocity of anteroposterior sway as a function of the forward shift of the point of gravity, but no differences showed up on the Fourier transformations (2). In all the previous posturographic investigations, all the postural measures were equally normal in the healthy subjects and in the diabetic patients without neuropathy.

The study presented in this article differs from the hitherto published research on postural problems in diabetic neuropathy in three aspects: 1) the diabetic target group was subdivided into three subgroups

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**Abbreviations:** ANOVA, analysis of variance; IBS, Interactive Balance System.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

**Table 1—Sample used in study**

Subject group	n	Age	Age at onset of illness	Duration of illness
Normal	30	51.1 ± 6.00	—	—
Older normal	8	58.8 ± 3.59	—	—
Neuropathy				
Severe	8	57.1 ± 9.50	40 ± 20	18 ± 14
Mild to moderate	12	48.7 ± 18.52	36 ± 13	13 ± 9
Absent	8	46.2 ± 14.45	34 ± 19	13 ± 6
Total for diabetic group	28	50.5 ± 11.90	37 ± 14	15 ± 11
Peripheral vestibular disturbances	19	50.1 ± 11.9	—	—
Central nervous system disturbance	13	46.6 ± 8.7	—	—
Whiplash	7	49.3 ± 8.1	—	—
Parkinson's disease	14	47.4 ± 10.5	—	—

Data are means ± SD and are expressed in years.

with severe, mild-to-moderate, and absent neuropathy; 2) in addition to a normal comparison group of healthy subjects, four clinical control groups of nondiabetic patients were used; and 3) the posturographic method used is based on patterns of interaction between five independent parameters obtained by the assessment of pressure fluctuations on four separate platforms (Interactive Balance System [IBS]; Tetrax, Ramat Gan, Israel).

## RESEARCH DESIGN AND METHODS

### Sample

A total of 28 diabetic patients were randomly sampled from the files of the Tel Hashomer Diabetic Clinic, Tel-Aviv, and subsequently invited to the clinic for reassessment of the actual status of their illness. On the basis of this checkup, patients were assigned to three subgroups—severe, mild-to-moderate, and absent neuropathy—as mentioned above. The method of staging of the diabetic neuropathy was based on the simple staging approach recently proposed by Dyck et al. (5), using the following criteria: NO, no signs or symptoms; MILD N1, asymptomatic neuropathy; MOD 2a, symptomatic neuropathy; and SEVERE 2b, symptomatic neuropathy, characterized by disabling symptoms and history of ulcer. Manifest symptoms such as pain or paresthesia were assessed by questionnaire. Asymptomatic neuropathy was diagnosed by assessing light-touch thresholds using a 10-gauge nylon monofilament applied to the plantar surface of both halluces and heels. In the present study, the diabetic patients were

staged into three groups, combining the stages of mild and moderate neuropathy.

In addition to a control group of normal subjects composed of 30 white- and blue-collar employees without any symptoms or history of illness or disability, the following clinical comparison groups were included in the sample: 1) 14 Parkinson's disease patients at stage II, as assessed by clinical evaluation; 2) 19 patients suffering from peripheral vestibular disturbances, as diagnosed by electro-nystagmography; 3) 13 patients with central nervous problems as documented by clinical neurological tests and examinations; and 4) 7 patients with documented whiplash syndrome after road accidents.

As shown in Table 1, both target and control groups consisted of upper-middle-aged subjects, and there were no significant age differences between the normal, clinical control, and diabetic groups. However, within the diabetic target group, the patients with severe neuropathy were conspicuously older (mean age = 57 years), which may be related to the relatively later onset and longer duration of their illness (Table 1). Although within the diabetic population the age differences were not significant ( $F(2, 26) = 1.93$ , NS)—and neither were the differences in onset and duration of the disease—there were significant differences in age between the severe neuropathic patients and the normal subjects ( $t = 3.37$ ,  $P = 0.003$ ). For this reason, a second small group of eight elderly healthy subjects, paired and matched by age with the severe neuropathic patients, was added to the sample.

Because there was no relationship between the sexes in the incidence or sever-

ity of neuropathy ( $\chi^2 [2 \text{ df}] = 2.83$ , NS) and because no sex difference in postural stability in adult populations between 20 and 60 years of age is reported in the literature (6), data for both sexes were combined. Height is not related to postural stability, as shown by numerous studies carried out by different authors and different methods and equipment (7–10). Consequently, height was not considered as a relevant intervening variable in this study. Weight, on the other hand, is automatically controlled for by the software of the IBS and does not need additional statistical treatment. Age correlates moderately, albeit not consistently, with the stability score of the IBS, but it has no effect on other parameters of the system (11). It was systematically taken into account in the context of elaborating and interpreting the results of this study (see above).

### Method

The posturographic examinations were carried out with the IBS, described in detail elsewhere (12). This system uses four separate platforms, each measuring the vertical pressure fluctuations induced by the two heels and toe parts, respectively. With this method, the following postural measures were obtained.

1. An index of general stability, which is equivalent to the traditional posturographic measures based on the assessment of the point-of-gravity excursions described above and was used in the previous studies.
2. Measures of weight distribution over the four platforms.
3. Measures of synchronization, reflecting the quality and efficiency of coordination movements between the heels and toes of each foot.
4. Fourier transformations derived from four independent wave signals and presented in the form of a spectrum, broken down into the following eight frequency bands: 0.01–0.1; 0.1–0.25; 0.25–0.35; 0.35–0.50; 0.50–1.00; 1.00–3.00; and 3.00 Hz and above. For practical purposes, these eight bands are collapsed into four, designated as low (0.01–0.1 Hz), medium-low (0.1–0.50 Hz), medium-high (0.50–1.00 Hz), and high (1.00–3.00 Hz). As shown by previous studies (12–16), deviant power in these four frequency bands—which the IBS software is able to display graphically and

**Table 2—Posturographic differences in general stability between diabetic, normal, and clinical control subjects**

Subject group	n	Position	
		Head straight, eyes open	Head back, eyes closed
Diabetic neuropathy			
Severe	8	35.2 ± 12.55‡	43.1 ± 24.4‡
Moderate	12	21.2 ± 16.78	25.8 ± 17.0†
Absent	8	16.2 ± 4.3	19.5 ± 6.68*
Normal	30	15.2 ± 4.8	14.8 ± 4.81
Peripheral vestibular disturbances	19	25.1 ± 20.97*	24.4 ± 13.9‡
Central nervous system pathology	13	22.5 ± 16.57*	28.0 ± 21.9†
Whiplash	7	33.0 ± 32.44†	18.3 ± 6.1
Parkinson's disease	14	17.1 ± 9.76	25.7 ± 4.0

Data are means ± SD. Posturographic differences within the diabetic group, as assessed by one-way ANOVA: for head straight, eyes open,  $F(3, 24) = 4.16$  ( $P = 0.03$ ); for head back, eyes closed,  $F(3, 24) = 3.99$  ( $P = 0.03$ ). \* $P < 0.05$ ; † $P < 0.01$ ; ‡ $P < 0.001$  vs. normal subjects. Higher scores indicate greater instability.

analyze statistically—is indicative of typical functional aberrations in the visual, somatosensory, vestibular, and central nervous subsystems of postural control. Low frequencies are linked with visual control, and they typically dominate normal steady and undisturbed posture. The medium-low frequency band (0.1–0.50 Hz) is sensitive to vestibular stress and disturbances. The medium-high frequencies (0.50–1.00 Hz) reflect somatosensory activity and postural reflexes mediated by the lower extremities. Bursts of high frequencies (over 1 Hz) are often induced by dysfunctions in the central nervous system.

5. A pattern analysis of the postural performance that compares the four measures described above on the following eight positions: head straight with eyes open; head straight with eyes closed; standing on elastic pads with eyes open; standing on elastic pads with eyes closed; head right with eyes closed; head left with eyes closed; head up with eyes closed; and head down with eyes closed (Table 3 and Fig. 1). (For a detailed description of the IBS, also referred in the literature as “Tetra-ataxiometry,” and for studies on its reliability and reproducibility see 12,15–17.)

**Procedure**

All diabetic subjects were examined using IBS on the occasion of being invited for clinical reassessment of their disease. The posturographic records for the normal and clinical control subjects were available from previous studies and were only scrutinized

for age and sex to match the diabetic target group.

**RESULTS** — As shown in Table 2, the present study generally confirms the results of the previous investigations. Subjects with severe neuropathy are significantly less stable than normal subjects and patients without neuropathy. Stability scores also discriminate within the diabetic sample, with the moderately neuropathic patients scoring, as expected, between the severe neuropathic and nonneuropathic patients (see one-way analysis of variance [ANOVA] on Table 2). On the relatively stressful position head up with eyes closed, the IBS score of stability turns out to be still more sensitive: moderately neuropathic subjects and even those not suffering from neuropathy were significantly more unstable than were normal control subjects.

Comparison with the clinical control group reveals that with the exception of patients with Parkinson's disease, all other clinical control subjects (patients with peripheral vestibular disorders, central nervous problems, or whiplash) show the same level of significant instability as diabetic patients with moderate and severe neuropathy when standing with head straight and closed eyes (classical Romberg). On the position of head up with eyes closed, however, subjects with severe neuropathy show a significantly higher instability than do whiplash and vestibular patients. Considering these findings, it seems that instability per se, although certainly being an important concomitant symptom of diabetic neuropathy, is only a marginally specific posturographic marker of this disease.

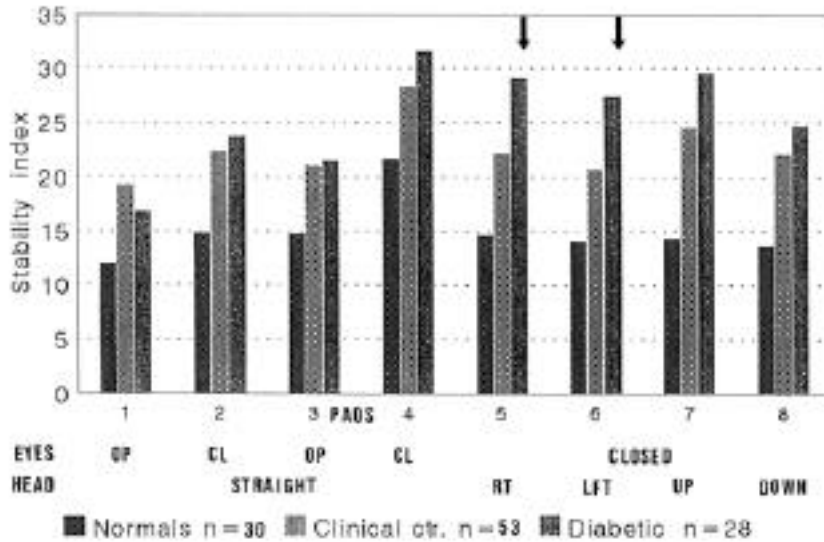
Further pattern analysis of the posturographic data revealed two additional aberrant characteristics of the diabetic target group that appear to be population-specific. First, although both diabetic patients and clinical control subjects are consistently and significantly less stable than normal subjects, stability was significantly more impaired in the left and right head turn in the diabetic patients than in clinical control subjects (Table 3, Fig. 1). Second, in a similar vein, when comparing the pattern of the Fourier spectrum, diabetic patients showed a significantly greater increase of sway power within the frequency range of 0.5–1.00 Hz than did clinical control subjects (Table 4, Fig. 2).

In light of these observations, it was plausible to inspect the diagnostic validity of the power scores on the frequency band 0.5–1.00 Hz at two positions, head right and head left. Results of this data elaboration are presented in Table 5 and Fig. 3. In

**Table 3—General stability for eight positions in normal, clinical control, and diabetic subjects**

Position	Normal	Clinical control	Diabetic	P
n	30	53	28	—
Head straight				
Eyes open	11.7 ± 4.70	18.1 ± 11.77	16.2 ± 8.51	NS
Eyes closed	15.2 ± 4.50	23.4 ± 19.60	23.3 ± 14.70	NS
Elastic pads				
Eyes open	14.5 ± 4.11	21.2 ± 10.47	20.4 ± 7.74	NS
Eyes closed	21.9 ± 8.21	28 ± 15.11	33.1 ± 16.57	NS
Head right	14.7 ± 4.32	20.7 ± 15.70	30.0 ± 22.75	0.05
Head left	14.7 ± 4.57	20.7 ± 15.19	27.2 ± 18.40	0.10
Head up	14.8 ± 4.81	25.0 ± 24.52	30.0 ± 19.31	NS
Head down	14.7 ± 5.35	21.8 ± 18.62	25.2 ± 14.41	NS

Data are means ± SD. P values (determined by t test) are for clinical control versus diabetic subjects.

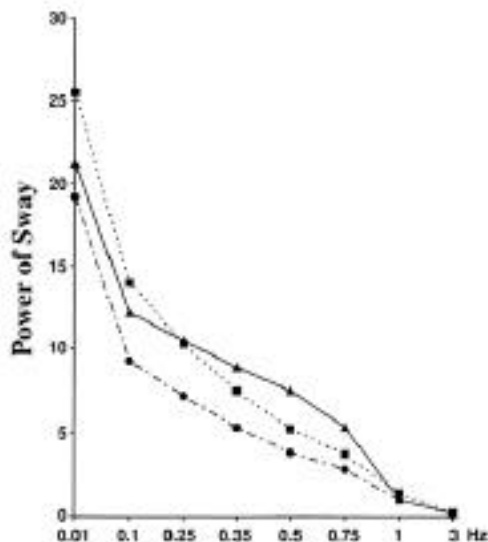


**Figure 1**—General stability in normal, clinical control, and diabetic subjects. Higher scores indicate worse stability.

**Table 4**—Patterns of Fourier spectral intensities of body sway at eight frequency bands in normal, clinical control, and diabetic subjects

Frequency (Hz)	Normal	Clinical control	Diabetic	P
n	30	53	28	
0.01–0.10	19.2 ± 4.63	25.5 ± 14.66	21.2 ± 6.68	NS
0.10–0.25	9.3 ± 2.35	14.0 ± 8.47	12.2 ± 2.18	NS
0.25–0.35	7.2 ± 1.46	10.3 ± 4.80	19.5 ± 3.10	NS
0.35–0.50	5.3 ± 11.1	7.5 ± 3.83	8.9 ± 3.84	NS
0.50–0.75	3.8 ± 1.10	5.2 ± 3.06	7.5 ± 3.5	0.01
0.75–1.00	2.8 ± 0.91	3.7 ± 2.93	5.3 ± 3.06	0.05
1.0–3.0	1.0 ± 0.29	1.4 ± 1.00	1.0 ± 0.42	NS
≥3.0	0.19 ± 0.05	0.23 ± 0.10	0.18 ± 0.03	NS

Data are means ± SD. P values (determined by t test) are for clinical control versus diabetic subjects.



**Figure 2**—Fourier spectral pattern of postural sway in normal (●), clinical control (■), and diabetic (▲) subjects.

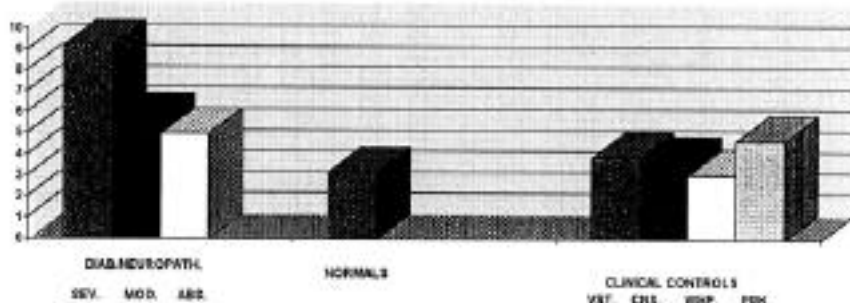
contrast to the stability measures, the power scores on these two positions turned out to represent a valid and specific posturographic sign of diabetic neuropathy. As can be seen in Table 5 and Fig. 3, these power scores discriminate significantly between normal and diabetic subjects at all levels of neuropathy, whereas clinical control subjects (except for vestibular pathology on the head right position) score within normal range. It should be noted that the power scores of diabetic patients without neuropathy are still significantly above normal level. The findings are age independent, as shown in Table 1 and in Table 6, with the latter demonstrating that the highly significant differences in the power spectral scores between elderly healthy subjects and severely neuropathic patients persist despite rigorously controlled age. On the other hand, it can be seen in Table 1 that the diabetic patients without neuropathy are even somewhat younger than the normal control subjects, while their spectral scores are significantly higher (Table 5). Also, results of a one-way ANOVA indicate that the power scores differentiate significantly between the levels of neuropathy within the diabetic sample (Table 5).

**CONCLUSIONS**—Although the results of this study confirm findings of previous research on the issue of postural instability in diabetic neuropathy, the IBS used in this investigation revealed that a specific parameter—power of sway at the frequency band of 0.5–1.00 Hz on positions requiring head turn in the horizontal plane—is not only highly sensitive to postural disturbances in cases of diabetic neuropathy as compared with normal subjects, but also differs between the diabetic neuropathy and other clinical groups. In addition, this parameter also seems to be a posturographic marker of high risk in patients not yet showing any clinical signs of the pathology. This might offer the possibility of using the IBS in the context of monitoring effects of preventive measures and early treatment of the disorder. It remains to be explained why power of sway within the high-medium frequency band reinforced by lateral head turn is affected by manifest or eventually imminent diabetic neuropathy. Although it is known that power of sway at 0.500–1.00 Hz is affected by somatosensory feedback (12–14) and thus might be sensitive to nerve conduction problems, it is less clear

**Table 5—Posturographic differences between diabetic, normal, and clinical control subjects in Fourier spectral power of body sway at frequency band 0.50–1.00 Hz**

Subject group	n	Position	
		Head right, eyes closed	Head left, eyes closed
Diabetic neuropathy			
Severe	8	12.7 ± 6.25‡	9.2 ± 6.09‡
Moderate	12	6.2 ± 4.24†	5.7 ± 3.02‡
Absent	8	5.5 ± 2.70‡	5.0 ± 1.47*
Normal	30	3.0 ± 1.11	3.2 ± 1.78
Peripheral vestibular disturbances	19	4.2 ± 2.25*	3.9 ± 2.00
Central nervous system pathology	13	3.8 ± 2.14	3.7 ± 1.61
Whiplash	7	3.4 ± 1.59	3.1 ± 1.92
Parkinson's disease	14	4.9 ± 5.86	4.7 ± 6.00

Data are means ± SD. Posturographic differences within the diabetic group, as assessed by one-way ANOVA: for head right, eyes closed,  $F(3, 24) = 6.21$  ( $P = 0.006$ ); for head left, eyes closed,  $F(3, 24) = 2.83$  ( $P = 0.07$ ). \* $P < 0.05$ ; † $P < 0.01$ ; ‡ $P < 0.001$  vs. normal subjects.



**Figure 3—Posturographic differences among diabetic, normal, and clinical control subjects on Fourier spectral power of body sway at frequency band 0.50–1.00 Hz. Abs., absent; CNS, central nervous system disturbance; Mod., moderate; Prk., Parkinson's disease; Sev., severe; Vst., peripheral vestibular disturbance; Whp., Whiplash.**

**Table 6—Posturographic differences between diabetic subjects with severe neuropathy and healthy elderly subjects closely matched by age on Fourier spectral power of body sway at frequency 0.5–1.00 Hz**

	n	Age	Head right	Head left
Severe neuropathy	8	57.1	12.7 ± 9.50*	9.2 ± 6.09*
Healthy elderly subjects	8	58.5	2.84 ± 0.59	2.88 ± 0.64

Data are means ± SD. \* $P < 0.001$ .

why horizontal shifts of the head should weaken the postural control in the target group. The only speculation we are able to offer in respect to this question is that lateral head turn induces a certain amount of unilateral stress on the leg opposite to the direction of the turn, which would be less tolerable when nerve conduction is impaired. Obviously, additional systematic

research is needed to validate and clarify these findings.

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