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Posture changes in diabetes mellitus

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Abstract
The weight distribution and postural sway was measured in diabetic subjects with, and without, neuropathy, and then compared with age and sex matched non-diabetic subjects using a cheap and highly portable sway plate – SwayWeigh. The SwayWeigh was found to be very practical and the results obtained confirmed the increased postural sway in the absence of proprioceptive information in neuropathy subjects. The study shows that peripheral neuropathy increases the postural sway especially in the absence of visual clues but this did not result in postural strategies causing significant limb load asymmetry.

Key words: Posture; Diabetes Mellitus; Neuropathy, Peripheral

Introduction

During upright stance the human body exhibits small body movements (sway) and balance is maintained as long as the vertical projection of the body's centre of mass is within the base of support bounded by the outer edges of the feet, and a number of models have been postulated.[1–5] Sensory information from vision, vestibular activity and the somatosensory system including muscle proprioception, joint and cutaneous afferents, are integrated in the central nervous system to coordinate the activities required for maintenance of the upright posture.[6–8] The sway control follows a hierarchical organization where visual clues override vestibular and proprioceptive ones, and in normal circumstances the relative weight of each of the components can be modified to maintain the optimal conditions required for equilibrium of stance.[6] Lesions in different parts of the nervous system result in different sway patterns, and the body employs different postural strategies in different conditions to maintain an upright stance when the equilibrium is threatened.[6,7] The postural strategies may include:

(1) Ankle strategy, where the primary force to move the centre of body mass occurs at the ankle. This strategy is seen in vestibular disorders.
(2) Hip strategy, where the primary force to move the centre of body mass occurs at the hip. This strategy is seen when proprioception is defective.
(3) Stepping or stumbling strategy, where the base of support has to move with the centre of mass. This strategy is seen when both the hip and ankle strategies are inadequate to maintain the stance, and can be seen in elderly subjects with loss of vibration sense at the ankle.

The sway during upright stance is also affected by the area of the base of support and hence the width of stance.[8–10] However, little is known if the different postural strategies have any effect on the way the body weight is distributed between the two legs, and between the heels and the balls of the feet. Normative data by Sackley and Lincoln shows that body weight is not distributed equally between the two feet, and a variation of up to 12 per cent was noted in 95 per cent of the 403 volunteers tested.[11] Blaszczyk *et al.* showed a significant increase in the asymmetry of body weight distribution in the elderly with eye closure.[12]

The present study intends to look mainly into the limb load asymmetry and postural sway in subjects with reduced somatosensation. Diabetes mellitus is a common condition, affecting about 15 per cent of the population over the age of 65 in developed countries. Peripheral neuropathy is a common complication of diabetes mellitus, and is present in more than 50 per cent of the non-insulin dependent patients over the age of 60 years.[13] Diabetic patients with neuropathy were, therefore, considered to be ideal candidates in term of ease of recruitment for the study. However, approximately 40 per cent of elderly healthy subjects may have decreased or asymmetrical lower extremity reflexes and slight impairment of position sense[14] and hence detailed neurological assessments were important to ensure that the control subjects included in the study did not have any neurological deficit.

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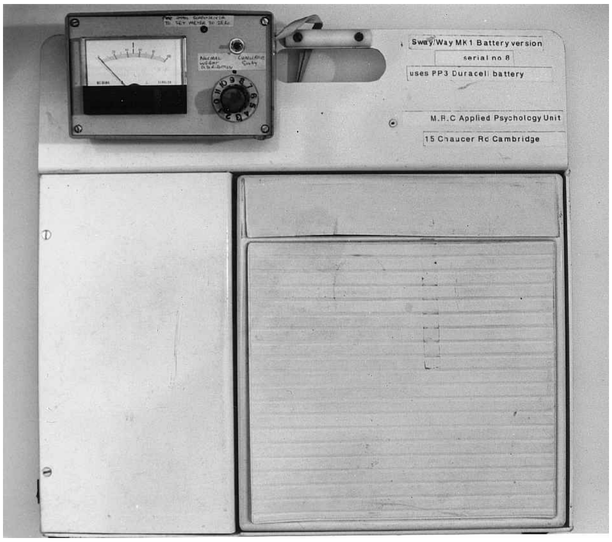

FIG. 1
Photograph of SwayWeigh balance platform.

The ability to demonstrate changes in postural sway and any significant asymmetry of body weight distribution by simple means will enable clinicians to suggest appropriate strategies to improve the reaction time in balance recovery in an efficient way.[12] SwayWeigh (Figure 1) is a simple piece of lightweight and portable equipment, differing from other commonly used balance platforms by having two separate platforms enabling measurement of the weight distribution in the two feet or two parts of the foot (heel *vs* forefoot), and measures sway in a different way as described in *Equipment*. There are no facilities for sway referencing or to alter the visual reference as is available in more advanced comprehensive systems for dynamic posturography.

The SwayWeigh platform works in a similar principle to the balance performance monitor, which is used by physiotherapists to assess and retrain patients with stroke, lower limb amputees and other patients with gait abnormalities.[15] SwayWeigh has been shown to be a useful tool in the assessment and evaluation of patients with balance problems.[16,17]

Methods

Equipment

The ‘SwayWeigh’ device was designed at the M.R.C. Applied Physiology Unit, Cambridge and is marketed by Raymar, Unit 1, Fairview Estate, Reading Road, Henley-on-Thames, Oxon, RG9 1LL. The Model MK1m used for the study runs on a readily available PP3 battery. The device consists of two main components, that are connected together with a cable as follows:

i) Feet plates. This part measures 45 × 42 cm with two areas, one for the right and the other for the left foot. One of the foot plate areas is a modified weighing scale covered by a pressure pad and the other one is a fixed platform. This part of the equipment has the battery compartment and the on–off switch.

ii) Meter. The meter measuring 16×10 cm is marked from 0 to 100 representing zero and 100 per cent of the body weight respectively with 50 divisions between them so that the smallest division represents two per cent of the body weight. The meter reading is indicated by the deflection of a needle. This section also has a calibration knob and a button for operating either the weight distribution mode or the integrated sway mode.

The principle of the apparatus is that when a person stands with one foot (the right foot was used in the study) on the load sensitive plate and the other on the fixed plate, the percentage of the weight distributed through the right foot will be registered by the meter. If a subject bears half the body weight on the right foot and the other half on the left foot while standing on the feet plate, with the right foot on the load sensitive plate and the left foot on the fixed plate the needle will show a meter reading of 50, when the device is set for the weight distribution mode. In the integrated sway mode the device shows the cumulative percentage of the body weight shifts, as a result of postural sway due to upright stance, to the foot on the load sensitive plate over a period of time. If the percentage of body weight to the foot over the load sensitive plate is, for example, 52 per cent, 54 per cent and 48 per cent at times t^1, t^2 and t^3 the integrated sway over time t^{1-3} towards the foot on the load sensitive plate is 2+4+0 = six per cent of the body weight. In the integrated sway mode the needle of the meter will be deflected at the specified time to the marking representing six per cent, i.e. three small divisions. There is also an option for connecting the equipment to a computer.

Subjects

All subjects recruited to the study were divided into three groups: *Group I*: Fifteen patients with non-insulin dependent diabetes mellitus and peripheral neuropathy that included seven males and eight females between 45 and 76 years (mean 61, median 62, S.D. 10.03), weighing between 50 and 85 kgs (mean 66.26, median 65, S.D. 11.79), and height varying from 142–180 cms (mean 163.53, median 162, S.D. 8.83). *Group II*: Fifteen patients with non-insulin diabetes mellitus but without peripheral neuropathy made up of seven males and eight females between 54 and 75 years (mean 63.6, median 64, S.D. 7.23), weighing between 45 and 82 kgs (mean 66.93, median 69, S.D. 10.08), and height varying from 150–175 cms (mean 160.60, median 160, S.D. 7.82). *Group III*: Non-diabetic controls made up of seven males and eight females between 56 and 75 years (mean 63.8, median 64, S.D. 5.7), weighing between 50 and 80 kgs (mean 69.80, median 70, S.D. 8.50), and height varying from 140–180 cms (mean 162.2, median 160, S.D. 10.52).

All the diabetic subjects in the study, in both groups I and II, attended the Manchester Diabetic Clinic. The diagnosis of neuropathy was confirmed by sensory and electro-physiological tests in addition to clinical judgement by physicians in the clinic.

Exclusion criteria

Subjects were included in the study following a detailed history and clinical examination to exclude the following conditions:

(1) Poor general medical condition such as anaemia, cardiac arrhythmia, postural hypotension, cardiac failure and dyspnoea when rested.
(2) Otological conditions which may result in vertigo and loss of balance such as discharging ears, previous mastoid and middle-ear surgery, positional vertigo, chronic labyrinthitis, acoustic neuroma and Ménière's disease.
(3) Significant ophthalmic conditions such as blindness, double vision, nystagmus, gross reduction of peripheral field of vision and gross reduction of visual acuity even with spectacles.
(4) Neurological problems (peripheral sensory neuropathy accepted only for group I) resulting in neuromuscular deficits such as vascular, traumatic and space-occupying lesion of the central nervous system, myaesthenia gravis, parkinsonism, motor neurone disease etc.
(5) Painful and deformed joints of the spine and lower limb, and history of joint replacements in the lower limb.
(6) Subjects on psychotropic or antiepileptic medications as well as those on vestibular sedatives.

Procedure

The SwayWeigh was placed on a level surface and the apparatus was calibrated. Patients stood upright on the load sensitive plate, so that it registered the whole body weight, and the meter reading was adjusted to 100 per cent. For all the experiments the feet were in the same position, the medial malleoli 8 cm apart and the feet parallel to one another, using a foot mat to ensure fixed stance width.

The subjects were asked to stand up as still as possible with the right foot on the load sensitive plate and the left foot on the fixed plate and looking straight ahead with the arms by the side of the body. After the subject had stood for 10 seconds the meter reading for the percentage of body weight recorded by the load sensitive plate under the right foot was noted. This gave the lateral weight distribution on the right foot with eyes open. Then the switch for the integrated sway was turned on and the cumulative sway of the weight shift to the right foot, as described previously, recorded directly from the meter reading over a period of 10 seconds. This reading gave the lateral sway with eyes open. The time was maintained accurately using a stopwatch. Once the lateral weight distribution and the lateral sway with eyes open were measured the subjects were asked to step down from the SwayWeigh. After a few seconds the subjects were asked to step back on the SwayWeigh again and both the lateral weight distribution and lateral sway measurements were repeated with the eyes closed. Anterior posterior weight distribution and sway were then carried out next, with eyes open and eyes closed, in a similar way except that the foot mat was placed with heel marks on the fixed platform and the balls of the feet on the load sensitive plate such that the arch of the foot was over the gap between the two plates. The whole procedure was repeated and two readings were recorded for each condition. The average of the two readings was analysed.

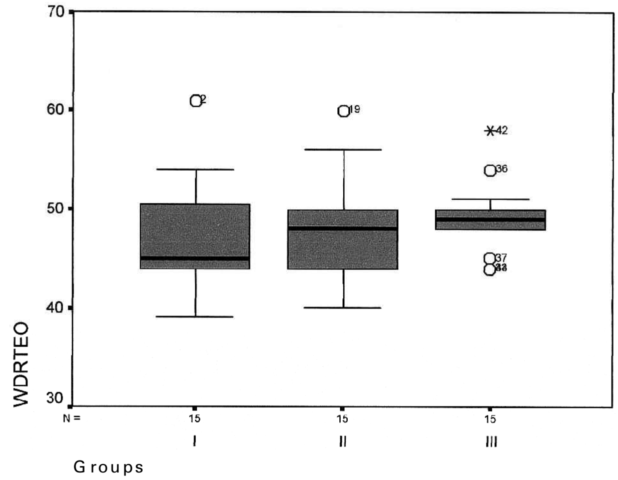

FIG. 2

Box plot to show the percentage weight distribution on the right foot with eyes open (WDRTEO) in the three groups of subjects.

Analysis

The data for the weight distributions on the right foot and the fore foot, and the lateral and anteroposterior sway with both the eyes open and closed were explored in the three groups using SPSS 10.1. The box plot of the weight and sway values in the three groups are shown in Figures 2–9. Non-parametric analysis of the data was carried out.

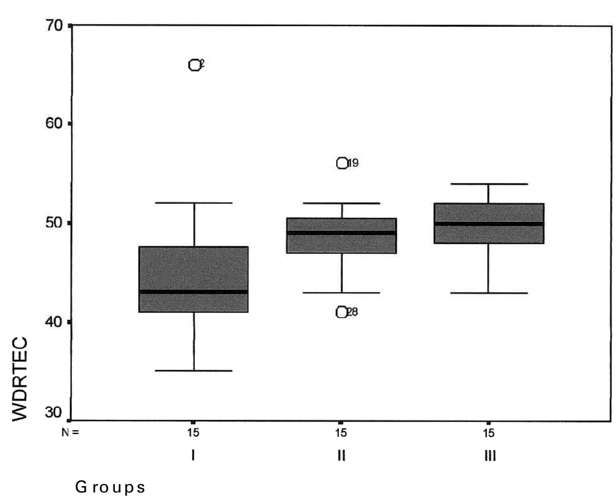

FIG. 3

Box plot to show the percentage weight distribution on the right foot with eyes closed (WDRTEC) in the three groups of subjects.

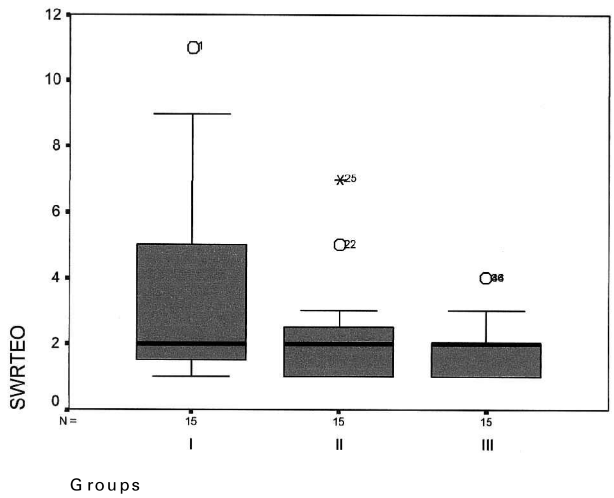

Fig. 4

Box plot to show the lateral sway towards right foot with eyes open (SWRTEO) in the three groups of subjects.

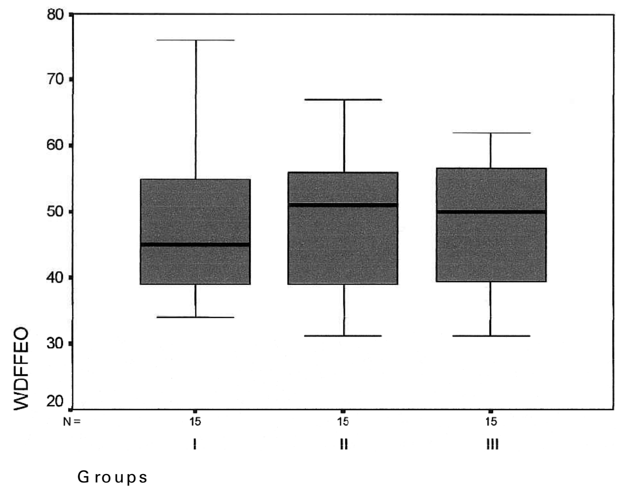

Fig. 6

Box plot to show the percentage weight distribution on the fore feet with eyes open (WDFFEO) in the three groups of subjects.

Results

Weight distribution

The median test showed no significant difference in the weight distributions either between the two legs (lateral weight distribution) or between the heels and forefoot (anterior weight distribution) between the three groups (Table I). The weight distributions within each group were analysed using the Wilcoxon signed rank test for matched pairs with eyes open and closed, and there were no significant differences in either the lateral or the anterior weight distribution (Table II).

Lateral Sway

The median test revealed significant difference in the lateral sway between the three groups with the eyes closed (Table III). This significant difference was found to be due to the increased sway of the diabetic neuropathy group with eyes closed compared to both the diabetic without neuropathy and the non-diabetic control subjects (Table IV). Eye closure caused a significant increase lateral sway in all the three groups but the increase was significantly higher in the neuropathic group (Table V).

Anteroposterior Sway

The median test showed a significant difference in the anteroposterior sway between the three groups with both eyes open and closed (Table III). Further statistical analysis using the Wilcoxon rank sum test showed that the significant difference was due to the increased anterior sway of the diabetic neuropathy group compared to both the diabetic without neuropathy and the non-diabetic control groups under both eyes open and eyes closed conditions. No differences were noted in the anteroposterior sway with either eyes open or closed between the diabetic without neuropathy subjects and the non-diabetic control subjects (Table VI and VII). Eye

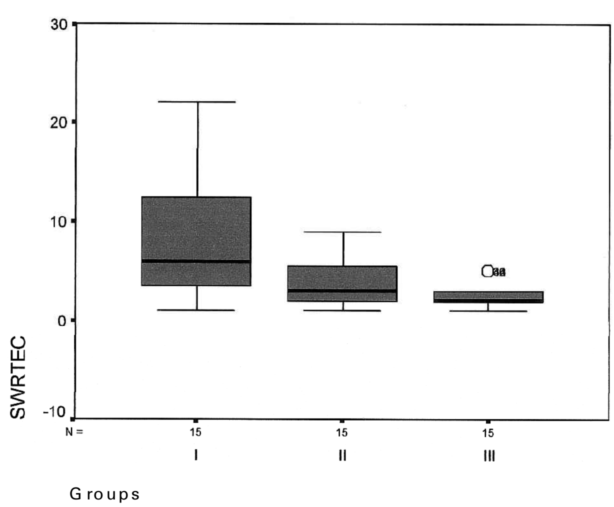

Fig. 5

Box plot to show the lateral sway towards right foot with eyes closed (SWRTEC) in the three groups of subjects.

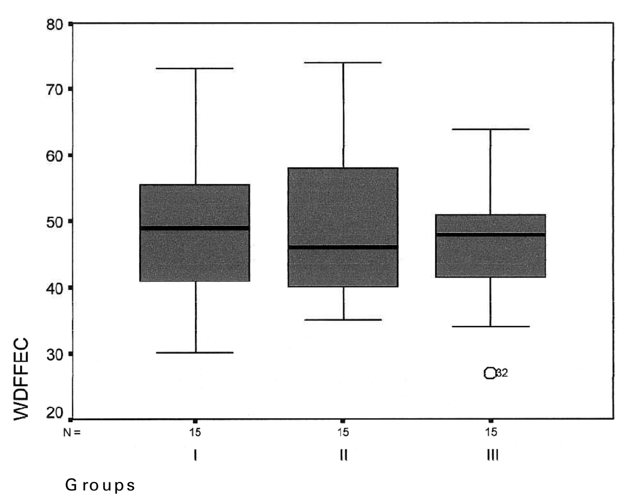

Fig. 7

Box plot to show the percentage weight distribution on the fore feet with eyes closed (WDFFEC) in the three groups of subjects.

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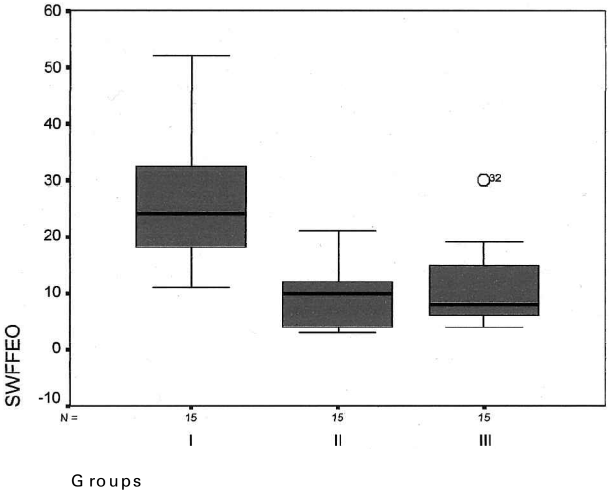

FIG. 8

Box plot to show the anteroposterior sway with eyes open (SWFFEO) in the three groups of subjects.

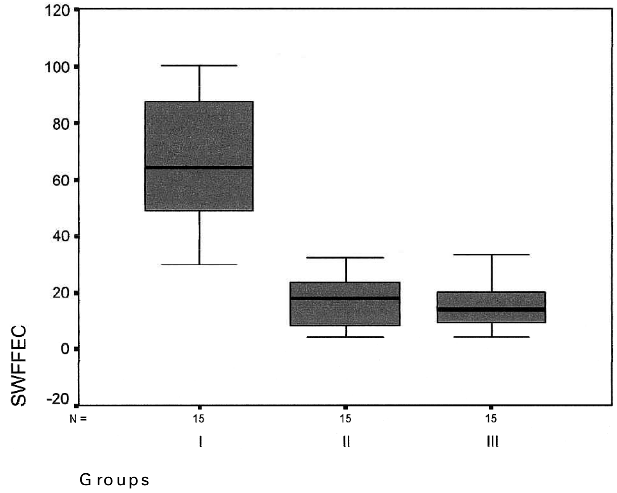

FIG. 9

Box plot to show the anteroposterior sway with eyes closed (SWFFEC) in the three groups of subjects.

closure caused a significant increase in the anteroposterior sway in all the three groups (Table V).

The mean values of the anteroposterior and lateral sway in the three groups with eyes open and closed are shown in Table VIII.

Sway, age, sex, height and weight

Correlation was sought between the weight distribution and sway measurements, and the age, sex, height and weight of the subjects participating in the study but no significant differences were found.

TABLE I

MEDIAN TEST COMPARING THE WEIGHT DISTRIBUTIONS BETWEEN THE THREE GROUPS

	% Weight right foot (lateral)		% Weight fore feet (anterior)	
	Eyes open	Eyes closed	Eyes open	Eyes closed
Number	45	45	45	45
Median	49.0000	48.0000	47.0000	48.0000
Chi-Square	.000	4.980	2.312	0.178
df	2	2	2	2
Asymptotic significance (2-tailed)	1.000	0.083	0.315	0.915

TABLE II

COMPARISON OF THE WEIGHT DISTRIBUTIONS WITHIN THE THREE GROUPS WITH EYES OPEN AND CLOSED, USING WILCOXON SIGNED RANK TEST FOR MATCHED PAIRS

	Group I		Group II		Group III	
	Lateral	Anterior	Lateral	Anterior	Lateral	Anterior
Z	–1.134	–1.121	–0.245	–0.503	–0.285	–0.409
Asymptotic significance (2-tailed)	0.257	0.262	0.806	0.615	0.776	0.682

TABLE III

MEDIAN TEST COMPARING THE LATERAL AND ANTERIOR SWAY BETWEEN THE THREE GROUPS

	Lateral Sway		Anterior Sway	
	Eyes open	Eyes closed	Eyes open	Eyes closed
Number	45	45	45	45
Median	2.0000	3.0000	13.0000	22.0000
Chi-Square	2.696	9.474	19.821	23.656
df	2	2	2	2
Asymptotic significance (2-tailed)	0.260	0.009	0.000	0.000

TABLE IV

WILCOXON RANK SUM TEST COMPARING THE LATERAL SWAY BETWEEN THE THREE GROUPS WITH EYES CLOSED

	Group I	Group II	Group I	Group III	Group II	Group III
Wilcoxon rank sum	289	176	311	154	237.5	227.5
$n_1 = n_2$	15	15	15	15	15	15
Significance	$p<0.05$		$p<0.001$		$p>0.05$	

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TABLE V

COMPARISON OF THE LATERAL AND ANTERIOR SWAY WITHIN THE THREE GROUPS WITH EYES OPEN AND CLOSED, USING WILCOXON SIGNED RANK TEST FOR MATCHED PAIRS

	Group I		Group II		Group III	
	Lateral	Anterior	Lateral	Anterior	Lateral	Anterior
Z	–3.189	–3.408	–3.220	–3.413	–2.889	–3.192
Asymptotic significance (2-tailed)	0.001	0.001	0.001	0.001	0.004	0.001

TABLE VI

WILCOXON RANK SUM TEST COMPARING THE ANTERIOR SWAY BETWEEN THE THREE GROUPS WITH EYES OPEN

	Group I	Group II	Group I	Group III	Group II	Group III
Wilcoxon rank sum	326.5	138.5	327	144.5	222	243
$n_1 = n_2$	15	15	15	15	15	15
Significance	$p<0.001$		$p<0.001$		$p>0.05$	

TABLE VII

WILCOXON RANK SUM TEST COMPARING THE ANTERIOR SWAY BETWEEN THE THREE GROUPS WITH EYES CLOSED

	Group I	Group II	Group I	Group III	Group II	Group III
Wilcoxon rank sum	342.5	121	343.5	121.5	236	229
$n_1 = n_2$	15	15	15	15	15	15
Significance	$p<0.001$		$p<0.001$		$p<0.05$	

TABLE VIII

THE MEAN ANTEROPOSTERIOR AND LATERAL SWAY VALUES, EXPRESSED AS PERCENTAGE OF THE BODY WEIGHT, OF THE THREE GROUPS WITH EYES OPEN AND EYES CLOSED

	Group I		Group II		Group III	
	Lateral	Anterior	Lateral	Anterior	Lateral	Anterior
Eyes open	3.7	26.4	2.2	9.8	1.8	11
Eyes closed	8.8	66.5	3.9	16.4	2.8	15.5

Discussion

The result shows that despite an increased anteroposterior sway in the diabetic neuropathic group compared to the diabetic without neuropathy and non-diabetic control groups there was no difference in the way the body weight was distributed to the two feet. The group of subjects that Blaszczyk *et al.*[12] showed to have significant difference in the weight distribution between the two legs were older than our diabetic neuropathy group. It is possible that in the older age group many kinds of compensatory changes in postural stability significantly increase the limb load asymmetry in preparation for a 'step strategy' in the event of a threatened loss of balance.[18] The situation is however very different in cases of stroke patients who favour bearing the body weight on the unaffected or stronger leg.[19]

The present study confirms previous findings by other authors that the weight of the body is not borne equally on the two sides of the body,[11,20] or between the heel and the fore feet. The inter subject variability in the weight distribution between the two legs does not seem to be explained by the dominant limb.[20,21] Our study did not look into the issue of the limb dominance. The study shows that absence of visual clues increase the lateral and the anteroposterior sway even in the non-diabetic control and the diabetic without neuropathy group where the somatosensation from the lower limbs and the vestibular functions are intact. However, absence of vision and impaired somatosensation in the diabetic neuropathy group increases the sway even further which agrees with established research findings of increased sway with altered or absent vision and altered surface.[7]

The mean anterior posterior sway was found to be significantly greater than the mean lateral sway. The increased magnitude of the anteroposterior sway has been known for some time and is due to the structure of the joints, for example the ankle and hips, and the actions of the muscles moving the body.

The location of the centre of mass affects the stability of the body with the body being less stable with a higher centre of mass. The postural sway will therefore increase with body height. The sway is usually higher in males due to the morphological characteristics.[22] In this study the heights and weights of the subjects were reasonably matched and hence no significant correlation was found between sway and height, weight or sex.

The SwayWeigh was very convenient to use and the study agrees with other researchers that this simple equipment can be used in patients with balance problems, mainly in monitoring the progress.[16,17] A small number of subjects were used in our study and there was a large inter-subject variation in the measurement of sway. A normative data from a large number of subjects would be helpful to establish cut-off points for normal subjects and those with balance disorders.

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