



Full length article

Effect of sensorimotor training on balance measures and proprioception among middle and older age adults with diabetic peripheral neuropathy

Irshad Ahmad^a, Majumi M. Noohu^b, Shalini Verma^a, Deepika Singla^b, Mohd Ejaz Hussain^{a,*}

^a Diabetes Research Group, Centre for Physiotherapy and Rehabilitation Sciences, Jamia Millia Islamia (A Central University), New Delhi, India

^b Human Performance Lab, Centre for Physiotherapy and Rehabilitation Sciences, Jamia Millia Islamia (A Central University), New Delhi, India

ARTICLE INFO

Keywords:

Static balance
Dynamic balance
COP range
COP sway
Rehabilitation
Balance training

ABSTRACT

Purpose: The aim of the study was to evaluate the effect of sensorimotor training on balance measures, and proprioception, among middle-aged and older adults with diabetic peripheral neuropathy (DPN).

Methods: A randomized controlled study with four parallel arms (two intervention groups and two control groups) was conducted at CPRS, Jamia Millia Islamia. Thirty-seven individuals were selected on the basis of inclusion and exclusion criteria. Of these, 16 middle-aged and 21 older adults were randomly allocated to intervention and control groups, respectively. Subjects in the intervention group were administered eight weeks (3days/week) of sensorimotor training, involving 10 different types of exercises, progressed from easy to hard every two weeks, along with diabetes and foot care education; subjects in control group received diabetes and foot care education only. Outcomes measures involved static and dynamic balance measures, centre of pressure (COP) range, COP sway, and proprioception, measured before and after eight weeks.

Results: Baseline measures showed significant age effect for timed up and go test (TUG) ($p = 0.002$), one leg stance (OLS) in eyes open (EO) and eyes closed (EC) ($p \leq 0.041$), COP range in front ($p = 0.007$), back ($p = 0.009$) and right direction ($p = 0.013$), COP sway with visual feedback in front-back direction ($p = 0.027$), COP sway without visual feedback in left-right direction ($p = 0.028$), and proprioception in right direction ($p = 0.026$). After intervention, OLS EO and EC on both legs showed significant time effect ($p \leq 0.003$), group effect as well as time \times group interaction ($p < 0.05$), and age effect and time \times age interaction ($p \leq 0.04$). Functional reach test, TUG, COP range, COP sway, and proprioception were found with significant time effect ($p < 0.03$), group effect, and time \times group interaction ($p \leq 0.035$). Age effect and time \times age interaction were found to be non-significant for all COP ranges and COP sway.

Conclusion: Sensorimotor training improved static and dynamic balance as well as proprioception measures after eight weeks of exercise intervention. Static balance showed greater improvement in the middle-aged than older aged adults, while dynamic balance and proprioception showed similar results for both.

1. Introduction

Diabetic peripheral neuropathy (DPN) occurs in 40%–59% of the total diabetic population [1,2] and age has been important risk factor for DPN as reported by many researchers [3–6]. While 27%–57% of the total DPN population lies between the ages of 50 and 60 years, this number soars up to 50%–100% when age is > 70 years [3,7]. Prevalence of DPN is the highest in middle-aged adults (40–60 years) and elderly adults (60+ years) with sensory loss such as vibration perception, pressure, pain, and joint position, thus effectively reducing control over balance and gait coordination [8].

Postural stability changes and clinical balance measures have been explained previously in young, middle, and older-aged groups [9,10].

Studies have reported balance deterioration in older adults [11], middle-aged adults [12], and in both age groups [13,14]. No study, has yet explored the differences in balance deteriorations among these age groups with DPN. Implementing balance interventions for the improvement of balance characteristics have earlier shown positive outcomes in DPN patients [15,16], and thus balance exercises have emerged as an effective physical intervention for improved balance characteristics in this population [17].

Sensorimotor training comprises facilitation of sensory inputs (proprioception and somatosensory inputs), correcting muscle imbalance, and ensuring correct motor program at the level of central nervous system. Balance exercises are well-established sensorimotor training consisting of static, dynamic, and functional approach to

* Corresponding author at: Centre for Physiotherapy and Rehabilitation Sciences, Jamia Millia Islamia (A Central University), New Delhi, 110025, India.

E-mail address: ehusain@jmi.ac.in (M.E. Hussain).

treating patients. Post balance training, improvements in balance measures in DPN patients have been reported in older adults [18,19], middle-aged adults [20], as well as in populations comprising both these age groups [21–24]. However, since these two groups could have different levels of balance impairments, further study is required to provide greater insight regarding customized, structured exercise interventions for each of these two age groups with DPN. A previous study explored age-related effect of exercise on physical health and ageing among middle-aged and older adults [25], but no such study has been conducted for the DPN population.

Thus, the aim of this study was to examine the differences in balance measures, and proprioception, in middle-aged and older adults with DPN, before and after eight weeks of sensorimotor exercise training.

2. Methods and materials

2.1. Study design

A randomized controlled trial with four parallel arms (two intervention groups and two control groups) was conducted. Middle-aged and older subjects with DPN were randomly allocated into either intervention or control groups. The intervention group received sensorimotor training, along with diabetes and foot care education, while the control group received diabetes and foot care education only. Outcome measures were assessed at the beginning of the study and after eight weeks. Ethical clearance was obtained from the Institutional Ethics Committee, Jamia Millia Islamia.

2.2. Participants

Thirty-seven individuals (aged 45–75 years) with DPN were recruited from: (a) Diabetic Care Clinic, Ansari Health Centre, and (b) Physiotherapy Clinic, CPRS, Jamia Millia Islamia. Inclusion criteria were (a) pre-diagnosed DM for seven years, (b) BMI 18.5–29.9 kg/m², (c) ≥ 2 DPN symptoms, (d) scored $> 2/13$ on MNSI questionnaire, and (e) scored $\geq 1/10$ on physical assessment including impaired vibration perception. Exclusion criteria were patients with: (a) foot ulcers, (b) orthopedic or surgical problem in a lower limb, (c) other neurological impairment, (d) major vascular complication, (e) severe retinopathy, (f) severe nephropathy, (g) inability to walk independently with or without an assistive device, and (h) receiving any structured supervised physiotherapy intervention. The procedures were explained to and written informed consent was received from each participant.

2.3. Outcome measures

2.3.1. Functional reach test (FRT)

Dynamic balance was assessed through FRT, by measuring the maximum distance that the subject could reach forward beyond one's own arm's length while maintaining a fixed base of support in the standing position [26]. Each subject was instructed to stand beside the wall with feet shoulder apart and arm stretched as far as possible, the distance of moving the knuckle's end was measured (in centimeters) without their taking step forward or touching the wall, using measuring tape. Practice trials were given to the subjects before experimental trials and the best of three experimental trials was used for analysis. FRT is a precise, valid, and reliable measure with an established sensitivity to change [26].

2.3.2. Timed up and go (TUG) test

TUG is a commonly used reliable test to examine functional mobility in community-dwelling, frail older adults [27,28]. It records the time taken (in seconds) to stand up from a standard armchair, walk a distance of 3 m, turn, walk back to the chair, and sit down. The total time taken to complete the circuit was measured using a stopwatch to the

nearest 0.01 s. Subjects performed the test barefoot and the best of three experimental trials was used for analysis. The time required to perform TUG is strongly related to the risk of fall. Healthy adults performing this test in ≤ 10 s have lesser risk of fall [27].

2.3.3. One leg stance (OLS)

OLS is a commonly used measure of static balance capabilities and has an excellent reliability in community-dwelling older people [29]. Each subject performed the test first with their dominant leg and then the other leg under two conditions: eyes open (90 s) and eyes closed (60 s). They were asked to stand on one leg with hands on the waist and lift the other leg at the level of the shin. The time was recorded (in seconds) using stopwatch till either the standing foot shifted in any way or the raised foot touched the ground. Practice trials were given to the subjects before experimental trials and the best of three experimental trials was used for analysis.

2.3.4. Postural assessment

Postural assessment was examined using Pedalo®-Sensamove Balance Test Pro with Miniboard, Utrecht, The Netherlands. Subjects were asked to stand barefoot with feet 4 cm apart and arms at the pelvis. They were then asked to tilt maximally in four directions (front, back, left, and right). This maximal tilting angle was recorded as COP range. Then the subjects were asked to stand on the balance board and maintain upright position for 30 s under two conditions: (a) a colored spot appeared on the computer screen and a verbal cue was given; this is known as COP sway with visual feedback (VF) and (b) only the verbal cue “maintain the upright position as you did earlier,” was given; this is known as COP sway without visual feedback (WVF). The height of the screen was kept at the eye level. The deviation in sagittal plane and front plane was measured as an average of “front” and “back,” and “left” and “right” deviation, respectively.

2.3.5. Proprioception

Proprioception was also examined using Pedalo®-Sensamove Balance Test Pro with Miniboard, Utrecht, The Netherlands. It records the difference between adjustable stimulus and reference stimulus [30,31] and has demonstrated excellent reliability in older subjects [32]. Subjects were familiarized with the testing procedure before actual testing. Each subject was asked to move his/her COP to the colored spot displayed on the screen with the help of a marker and to remember the spot and then to reach the spot without the marker on the screen. The difference in the angle was measured between the reference stimulus and the actual position. Measurements were taken in four directions (front, back, right, and left).

2.4. Interventions

2.4.1. Sensorimotor training

The exercise was conducted thrice a week for eight weeks (total 24 sessions). Each session comprised of 10-min warm-up, followed by 50–60 min of exercise, followed by 5–10 min of cool-down. Warm-up exercise used cycle ergometer or treadmill at the intensity of 50%–60% HR_{max}, where HR_{max} = 206.9 – 0.69 × age (years). Sensorimotor training comprised wall slides, core exercises, balance exercises on unstable surface (Thera band® stability trainer), and gait training (different patterns of walking) (Appendix 1). Cool-down exercises included deep breathing, abdominal breathing, and mild stretching. Exercise participation was modified, postponed, or stopped based on the current guidelines of American Diabetes Association. The volume of exercise was increased after three sessions. In addition to this, the exercise level was increased after every two weeks if tolerated.

2.4.2. Diabetes and foot care education

Diabetes and foot care education sessions were conducted once in two weeks for 30 min. The session comprised dispensing information

about understanding the complications of diabetes, diabetes management, and foot care guidelines, along with dietary counseling. The instruction was provided by a professional physiotherapist specialized in diabetes. Subjects were allowed to continue with their daily activities (walking or jogging).

2.5. Statistical analysis

Statistical analysis was done using SPSS 21. Univariate ANOVA was used to analyze baseline data considering group (intervention and control groups) and age (< 60 and ≥ 60 years) as between-factors. Three-way repeated measure ANOVA was used considering the baseline and post-training values as within-factors, and group and age as between-factors. Three-way repeated measure ANCOVA was used for variables if a baseline value was found to be significantly different considering the baseline values as covariate. The level of significance for the statistical tests was set at $p \leq 0.05$ with the confidence interval of 95%.

To examine the effect of sensorimotor training on balance in patients with DPN, a post-hoc power analysis was conducted for the sample size of 37, using software G. Power 3.1.9.4. Based on the changes in dynamic balance (measured using FRT) following sensorimotor training, the effect size observed in the present study ($d = 0.8$ for middle-aged; $d = 1.3$ for older adults) revealed a power of 0.9, at an alpha level = 0.05.

3. Results

Demographic characteristics showed age effect in diabetic duration, number of falls, and physical assessment of MNSI ($p < 0.05$) while group effect was found only in HbA1c ($p = 0.02$) (Table 1).

Baseline measures showed significant age effect for TUG ($p = 0.002$), OLS EO and EC on both legs ($p \leq 0.041$), COP range front ($p = 0.007$), back ($p = 0.009$), and right ($p = 0.013$), COP sway VF front-back ($p = 0.027$), COP sway WVF left-right ($p = 0.028$), and proprioception right ($p = 0.026$) (Table 2). Significant group effect was found in COP range front ($p = 0.023$) and proprioception front ($p = 0.034$) (Table 2).

FRT and TUG showed significant time effect ($p \leq 0.013$), group effect ($p < 0.001$), and time×group interaction ($p \leq 0.046$), indicating that FRT and TUG values improved for the intervention group, in comparison with the control group, regardless of age (Table 3). OLS EO left leg and EC right and left leg showed significant time effect ($p \leq$

0.003), group effect as well as time×group interaction ($p \leq 0.043$), age effect, and time×age interaction ($p \leq 0.04$). OLS EO right leg showed only significant group effect and time×group interaction ($p = 0.003$) (Table 3).

COP range front, back, left, and right revealed significant time effect ($p \leq 0.002$), group effect, and time×group interaction ($p \leq 0.004$). Age effect and time×age interaction was found to be non-significant for all COP ranges (Table 3). COP sway VF front-back was found significant only for time effect ($p = 0.027$). COP sway WVF front-back was found significant for time effect ($p = 0.002$) and age effect ($p = 0.035$), while COP sway WVF left-right only showed significant time effect ($p = 0.008$) (Table 3).

Proprioception in all directions showed significant time effect ($p \leq 0.021$), and time×group effect ($p \leq 0.04$). Group effect was found significant for proprioception front and right ($p = 0.038$) (Table 4).

4. Discussion

The present study examined differences in proprioception and static as well as dynamic measures of balance among middle-aged and older adults with DPN. Also, sensorimotor training group exhibited significant improvement in FRT, TUG, COP range, and proprioception, irrespective of age; while OLS EO and EC in older adults showed significantly smaller changes when compared with middle-aged DPN patients.

4.1. Effect of age on balance measures, and proprioception

The current study found significant decrease in OLS with EO and EC on both legs, lesser FRT (non-significant), and increased TUG score in older adults, when compared with middle-aged DPN adults. Steffen and colleagues have also found increased score of TUG with increase in age irrespective of the gender [33], while Condron et al. found significant differences between young healthy and both old-aged fallers and old-aged healthy [34]. Vereeck et al. reported normative data for those aged from 20 to 80 years and showed decrease trend of OLS, standing on foam, and tandem Romberg [10].

Our study found that older DPN patients fall more often than middle-aged ones. Previous studies have reported that subjects with more number of falls had diminished balance control [35,36]. The assessment for neuropathy evaluation (MNSI: physical assessment) in the present study revealed significantly higher values in older adults with DPN (although MNSI was not used as a tool to measure the severity of

Table 1 Demographic characteristics of DPN patients.

Variables	< 60 years		≥ 60 years		Age Difference p-value	Group Difference p-value
	Intervention group (n = 8) Mean ± SD	Control group (n = 8) Mean ± SD	Intervention group (n = 12) Mean ± SD	Control group (n = 9) Mean ± SD		
No. of subjects (M/F)	6/2	4/4	8/4	6/3		
Age (year)	52.87 ± 4.58	51.75 ± 5.7	66.75 ± 4.15	64.77 ± 4.6	< 0.001*	0.333
Height (cm)	167.77 ± 9.57	158.48 ± 5.75	161.69 ± 7.64	163.4 ± 11.17	0.842	0.202
Weight (Kg)	70.51 ± 12.44	65.49 ± 4.61	63.95 ± 14.15	70.19 ± 16.12	0.831	0.888
BMI (Kg/m ²)	24.97 ± 2.89	26.16 ± 2.61	24.31 ± 3.63	26.23 ± 4.64	0.807	0.203
Diabetic duration	11.06 ± 3.7	12.25 ± 4.92	15.75 ± 7.02	15.77 ± 6.72	0.046*	0.761
HbA1c	7.76 ± 1.33	9.32 ± 1.8	8.27 ± 1.16	9 ± 1.34	0.842	0.02*
RBG	143.13 ± 37.97	199 ± 71.56	202.08 ± 64.74	207 ± 23.04	0.072	0.101
No. of comorbidities	0.25 ± 0.46	0.62 ± 0.74	1 ± 0.85	0.77 ± 0.83	0.083	0.764
No. of falls	0.13 ± 0.35	0.38 ± 0.51	1 ± 0.95	0.89 ± 0.60	0.005*	0.764
Medications (Oral/Insulin/Both)	6/1/1	4/0/4	7/1/4	6/1/2	–	–
Smoker or tobacco intake (Y/N)	1/7	4/4	2/10	3/6	–	–
MNSI (Q)	3.87 ± 1.35	4 ± 2.32	4.5 ± 1.88	5 ± 1.5	0.166	0.656
MNSI (Ph)	2.75 ± 0.75	2.25 ± 0.53	3.29 ± 1.38	3.22 ± 1.03	0.036*	0.418

M: Male; F: Female; BMI: Body mass index; HbA1c: Glycosylated hemoglobin; RBG: Random blood glucose level; MNSI: Michigan neuropathy screening instrument; Q: Questionnaire; Ph: Physical assessment.

Table 2
Baseline comparison of the balance measures.

Variables	< 60 years		≥ 60 years		Difference due to age p-value	Difference due to group p-value
	Intervention group (n = 8)	Control group (n = 8)	Intervention group (n = 12)	Control group (n = 9)		
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD		
FRT (cm)	35.57 ± 5.73	31.13 ± 5.61	31.16 ± 6.3	29.6 ± 3.61	0.114	0.11
TUG (sec)	9.9 ± 1.69	10.52 ± 1.14	11.53 ± 2.35	13.46 ± 2.41	0.002*	0.069
OLS (sec)						
EO (Right)	34.12 ± 18.07	28.22 ± 23.48	15.11 ± 14.18	8.16 ± 4	0.001*	0.238
EO (Left)	28.76 ± 17.24	24.63 ± 21.89	13.17 ± 11.78	6.81 ± 3.3	0.002*	0.289
EC (Right)	7.76 ± 4.44	6.29 ± 3.92	5.01 ± 2.06	3.37 ± 1.65	0.01*	0.141
EC (Left)	6.49 ± 3.31	7.43 ± 6.7	5.02 ± 2.88	3.37 ± 1.43	0.041*	0.787
COP Range (degree)						
Front	18.55 ± 1.82	16.12 ± 3.3	15.6 ± 4.11	12.74 ± 3.11	0.007*	0.023*
Back	15.85 ± 2.22	14.97 ± 2.82	13.14 ± 3.78	12.16 ± 2.31	0.009*	0.357
Left	17.28 ± 2.44	15.3 ± 3.79	15.52 ± 3.98	13.5 ± 2.75	0.124	0.085
Right	18.16 ± 1.88	16.55 ± 1.81	15.15 ± 3.17	14.26 ± 4.26	0.013*	0.226
COP Sway VF						
Front-back	0.47 ± 0.25	0.45 ± 0.31	0.65 ± 0.35	0.78 ± 0.34	0.027*	0.646
Left-right	0.49 ± 0.2	0.37 ± 0.2	0.55 ± 0.26	0.59 ± 0.32	0.109	0.663
COP sway WVF						
Front-back	0.66 ± 0.33	0.64 ± 0.28	0.82 ± 0.43	0.88 ± 0.36	0.111	0.873
Left-right	0.62 ± 0.31	0.5 ± 0.16	1.05 ± 0.74	0.87 ± 0.54	0.028*	0.393
Proprioception (Angle difference)						
Front	6.17 ± 4.75	8.73 ± 3.05	6.61 ± 2.59	9.36 ± 4.02	0.658	0.034*
Back	10.91 ± 6.74	8.97 ± 5.07	10.16 ± 4.89	9.83 ± 8.61	0.979	0.599
Left	9.12 ± 6.76	8.07 ± 4.02	10.74 ± 5.58	10.87 ± 5.11	0.234	0.804
Right	7.35 ± 5.27	4.71 ± 3.65	9.79 ± 5.32	10.67 ± 6.78	0.026*	0.631

FRT: Forward reach test; TUG: timed up and go test; OLS: One leg stance; EO: Eyes open; EC: Eyes closed; COP range: Centre of pressure range; COP sway VF: Centre of pressure sway with visual feedback; COP sway WVF: Centre of pressure without visual feedback; SD: standard deviation; *: significant levels.

neuropathy); middle-aged adults were mostly found with mild to moderate neuropathy, while older adults had mild to severe neuropathy. The present study also revealed that older DPN adults had longer duration of diabetes; the association between diabetic duration and prevalence of neuropathy has been confirmed earlier [2,37,38]. Further, the decline in peripheral sensation associated with neuropathy has been strongly linked with falls and balance impairments for individuals with type 2 diabetes (T2DM) [39,40]. Thus, reduced balance control in older adults with DPN could be a result of decrease in general physical functions due to ageing, reduced position sense/peripheral sensation, neurological control, and fear of falls [19,41].

This study also revealed decrease in COP range (front, back, and right) as well as COP sways VF (front-back) in older adults as compared to middle-aged adults with DPN, while no difference was found in COP sway VF (left-right) between the two age groups. Similar findings have been observed previously, where differences were found in COP range as well as COP sway directions between elderly adults and young adults [42–44]. It may further be added that antero-posterior stability is more related to ankle and sole muscles, while left-right stability is provided by hip abductor and adductor muscles [20]. Motor impairment involved in DPN patients are in distal to proximal pattern, indicating that ankle muscles get involved earlier than the muscles around the hip joint do. On the other hand, COP sway WVF front-back direction showed no significant difference between the middle-aged and older adults with DPN. Hence, in the absence of cues, subjects held their position by increasing the co-contraction of ankle and sole muscles, thus increasing joint stiffness, and which leads to decrease in postural motion [45–47].

4.2. Exercise effect on balance measures, proprioception and reaction time

The intervention groups showed improved FRT and TUG regardless of age in our study. Previous studies have reported similar results with 6, 8 or 12 weeks of balance exercises, and observed improved dynamic balance (FRT, TUG, and walk over beam) [18,19,21]. However, Richardson et al. found no improvement with three weeks of balance exercises [23]. Most of the subjects in the current study had TUG value

between 9.1 and 13.4 s. A TUG value that is < 10 s indicates low risk of falls, and > 14 s indicates high risk of falls [27]. While direct assessment of falls was not done, the exercises reduced the risk to fall in adults who are ≥ 60 years.

Also, the current study found improved static balance by evaluating OLS with EO and EC condition in both legs, for which greater improvement was achieved by middle-aged adults than the older age adults with DPN (Fig. 1). Song et al. and Lee et al. also report increase in OLS after balance exercises [18,19] whereas Kruse et al. did not find any significant changes after intervention [22]. Rohjani-Shirazi et al. also found enhanced OLS with EO and EC in both limbs with two different types of balance training [48]. Less improvement in static balance (OLS) in older group as compared to middle-aged group could be due to physiological factors of ageing, such as the difference in the production of muscular power, decrease in the ability of neuromuscular control, and greater severity of diabetic neuropathy with increasing age. The affliction of OLS performance was found to be severe for older adults before intervention thus the reserve start of the OLS in older adults could be the reason for lesser change. Dynamic balance did not show significant difference between the two age groups after intervention which could be due to the fact that exercises were more focused on the static component, exhibiting the rule of specificity. To the best of our knowledge, no study has yet reported the effects of sensorimotor exercise by studying middle-aged and older DPN adults independently.

COP range showed significant change after intervention in all directions: front, back, left, and right. Morrison et al. found similar results in DM as well as DPN patients [49]. The current study demonstrates that improvement in older adults was insignificantly higher than in middle-aged adults, which could be attributed to the maximal scope of improvement in COP range in older adults when compared with middle-aged adults. COP sway revealed significant time effect in VF front-back, VF left-right (close to significant), WVF front-back and WVF left-right; also, the intervention group showed greater but insignificant positive change than the control group (Appendix 2). Previous studies have also found significant improvement in the sway index in sagittal as well as in frontal planes, after balance exercises [19,21,49,50]. Akbari

Table 3
Results of balance measures using 3 way ANOVA.

Variables	< 60 years		≥ 60 years		Time (T) effect	Age (A) effect	Group (G) effect	T × G effect	T × A effect	A × G effect
	Intervention group (n = 8)	Control group (n = 8)	Intervention group (n = 12)	Control group (n = 9)						
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	p-value	p-value	p-value	p-value	p-value	p-value
FRT (cm)					< 0.001*	0.111	0.024*	0.046*	0.49	0.417
Baseline	35.57 ± 5.73	31.13 ± 5.61	31.16 ± 6.3	29.6 ± 3.61						
8th week	37.86 ± 4.28	31.85 ± 4.81	34.22 ± 5.97	30.72 ± 1.47						
TUG (sec)					0.013*	0.577	< 0.001*	< 0.001*	0.577	0.209
Baseline	9.9 ± 1.69	10.52 ± 1.14	11.53 ± 2.35	13.46 ± 2.41						
8th week	9.16 ± 1.41	10.46 ± 1.15	9.75 ± 1.9	12.78 ± 2.07						
OLS (sec)										
EO (Right)					0.091	0.32	0.003*	0.003*	0.32	0.059
Baseline	34.12 ± 18.07	28.22 ± 23.48	15.11 ± 14.18	8.16 ± 4						
8th week	49.11 ± 26.71	27.43 ± 23.83	20.2 ± 15.03	9.06 ± 2.62						
EO (Left)					0.002*	0.046*	0.043*	0.043*	0.046*	0.526
Baseline	28.76 ± 17.24	24.63 ± 21.89	13.17 ± 11.78	6.81 ± 3.3						
8th week	38.98 ± 20.05	26.79 ± 19.53	17.45 ± 11.04	7.84 ± 3.56						
EC (Right)					0.003*	0.034*	0.009*	0.009*	0.034*	0.012*
Baseline	7.76 ± 4.44	6.29 ± 3.92	5.01 ± 2.06	3.37 ± 1.65						
8th week	12.47 ± 5.06	5.94 ± 4.82	5.58 ± 2.35	4.31 ± 1.39						
EC (Left)					< 0.001*	0.001*	< 0.001*	< 0.001*	0.001*	0.127
Baseline	6.49 ± 3.31	7.43 ± 6.7	5.02 ± 2.88	3.37 ± 1.43						
8th week	10.37 ± 3	7.26 ± 3.01	6.08 ± 2.87	3.81 ± 1.34						
COP Range (degree)										
Front					< 0.001*	0.554	0.003*	0.003*	0.554	0.3
Baseline	18.55 ± 1.82	16.12 ± 3.3	15.6 ± 4.11	12.74 ± 3.11						
8th week	20.05 ± 1.99	16.33 ± 2.87	17.07 ± 3.28	14.37 ± 2.71						
Back					< 0.001*	0.752	0.01*	0.01*	0.752	0.62
Baseline	15.85 ± 2.22	14.97 ± 2.82	13.14 ± 3.78	12.16 ± 2.31						
8th week	17.42 ± 1.85	15.58 ± 3.11	16.09 ± 2.98	13.63 ± 1.83						
Left					0.002*	0.115	0.024*	0.367	0.535	0.727
Baseline	17.28 ± 2.44	15.3 ± 3.79	15.52 ± 3.98	13.5 ± 2.75						
8th week	18.18 ± 2.4	16.25 ± 3.39	17.48 ± 2.79	14.21 ± 2.27						
Right					< 0.001*	0.294	0.004*	0.004*	0.294	0.791
Baseline	18.16 ± 1.88	16.55 ± 1.81	15.15 ± 3.17	14.26 ± 4.26						
8th week	19.88 ± 1.09	17.08 ± 2.65	17.82 ± 2.3	15.64 ± 2.4						
COP Sway VF										
Antero-posterior					0.027*	0.841	0.245	0.245	0.841	0.072
Baseline	0.47 ± 0.25	0.45 ± 0.31	0.65 ± 0.35	0.78 ± 0.34						
8th week	0.45 ± 0.22	0.40 ± 0.33	0.52 ± 0.22	0.72 ± 0.26						
Left-right					0.078	0.062	0.935	0.128	0.854	0.333
Baseline	0.49 ± 0.2	0.37 ± 0.2	0.55 ± 0.26	0.59 ± 0.32						
8th week	0.38 ± 0.11	0.36 ± 0.23	0.46 ± 0.23	0.59 ± 0.29						
COP sway WVF										
Antero-posterior					0.002*	0.035*	0.415	0.141	0.797	0.499
Baseline	0.66 ± 0.33	0.64 ± 0.28	0.82 ± 0.43	0.88 ± 0.36						
8th week	0.48 ± 0.17	0.53 ± 0.29	0.61 ± 0.21	0.84 ± 0.29						
Left-right					0.008*	0.47	0.672	0.672	0.47	0.409
Baseline	0.62 ± 0.31	0.5 ± 0.16	1.05 ± 0.74	0.87 ± 0.54						
8th week	0.59 ± 0.29	0.41 ± 0.19	0.84 ± 0.46	0.76 ± 0.46						

FRT: Forward reach test; TUG: time up and go test; OLS: One leg stance; EO: Eyes open; EC: Eyes closed; COP range: Centre of pressure range; COP sway VF: Centre of pressure sway with visual feedback; COP sway WVF: Centre of pressure without visual feedback; SD: standard deviation; *: significant levels.

et al. and Silva et al. have reported significantly improved sway in antero-posterior direction [20,51] while Salsabili et al. found significant changes in antero-posterior as well as medio-lateral sway index, both with and without biofeedback [24]. In our study, the control group of middle-aged DPN showed some improvement in COP sway. This could be attributed to the fact that subjects were engaged in some kind of exercise (walking or jogging) during the study as Morrison et al. have showed that aerobic exercises improve COP mean and SD in T2DM as well as neuropathic subjects [49].

In our study, proprioception was found improved in both age groups after eight weeks of intervention. There was a reduction in the position reproduction errors in front, back, left, and right direction in both age groups. Previously, Song et al. reported improvement in trunk

proprioception after eight weeks of balance exercise in DPN subjects [19]. Since lack of proprioception is responsible for postural instability in DPN, improved proprioceptive feedback enhances postural/balance control in DPN patients.

Our study is not without limitations though, which should be recognized. While the addition of control group provided for comparison in-between the groups, this group was not controlled for home exercises. Further, a greater sample size would have provided for higher power for some of the variables. Most of the subjects participating in the study were mild to moderate neuropathic. Severely neuropathic subjects were few and were found mostly in older age group, hence limiting the generalizability of the results to entire middle-aged and older age population with DPN. Future research should focus on

Table 4
Results of proprioception using 3 way ANOVA.

Variables	< 60 years		≥ 60 years		Time (T) effect	Age (A) effect	Group (G) effect	T × G effect	T × A effect	A × G effect
	Intervention group (n = 8)	Control group (n = 8)	Intervention group (n = 12)	Control group (n = 9)						
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	p-value	p-value	p-value	p-value	p-value	p-value
Proprioception (Angle difference)										
Front					0.001*	0.705	0.038*	0.038*	0.705	0.701
Baseline	6.17 ± 4.75	8.73 ± 3.05	6.61 ± 2.59	9.36 ± 4.02						
8th week	4 ± 2.74	7.31 ± 4.55	4.92 ± 1.98	7.34 ± 4.36						
Back					0.017*	0.567	0.82	0.04*	0.181	0.584
Baseline	10.91 ± 6.74	8.97 ± 5.07	10.16 ± 4.89	9.83 ± 8.61						
8th week	6.73 ± 4.5	7.5 ± 4.84	7.57 ± 3.52	10.74 ± 7.63						
Left					0.021*	0.542	0.22	0.015*	0.182	0.954
Baseline	9.12 ± 6.76	8.07 ± 4.02	10.74 ± 5.58	10.87 ± 5.11						
8th week	5.07 ± 3.66	10.15 ± 5.64	5.53 ± 3.32	9.06 ± 7.81						
Right					0.01*	0.695	0.038*	0.038*	0.695	0.95
Baseline	7.35 ± 5.27	4.71 ± 3.65	9.79 ± 5.32	10.67 ± 6.78						
8th week	3.92 ± 2.91	5.78 ± 3.34	5.15 ± 2.86	8.27 ± 6.48						

SD: standard deviation; *: significant levels.

assessing the efficacy of sensorimotor training in severely affected diabetic neuropathy patients in both the age groups.

5. Conclusion

It is concluded that in DPN patients, sensorimotor training improves static and dynamic balance measures after eight weeks. Static balance shows greater improvement in the middle-aged than older age group, while dynamic balance and proprioception shows similar improvement in both age groups.

Declaration of Competing Interest

We certify that we have participated sufficiently in the intellectual content, conception and design of this work or the analysis and interpretation of data, as well as the writing of the manuscript, to take public responsibility for it and have agreed to have our name listed as a

contributor. We believe the manuscript represents valid work. Each author confirms they meet criteria for the authorship. This manuscript has not been published or considered for publication elsewhere, except as describing in the covering letter. We will provide the data/information or will cooperate fully in obtaining on which the manuscript is based, for examination by the editors or their assignees. We will attest that, if requested by the editors. The authors have no conflicts of interest with financial or non-financial interest.

We give the rights to the corresponding author to make necessary changes as per the request of the journal, do the rest of the correspondence on our behalf and he will act as the guarantor for the manuscript on our behalf.

Acknowledgements

We express our deep gratitude to the participants for their enthusiasm and willingness to participate in this study. We acknowledge

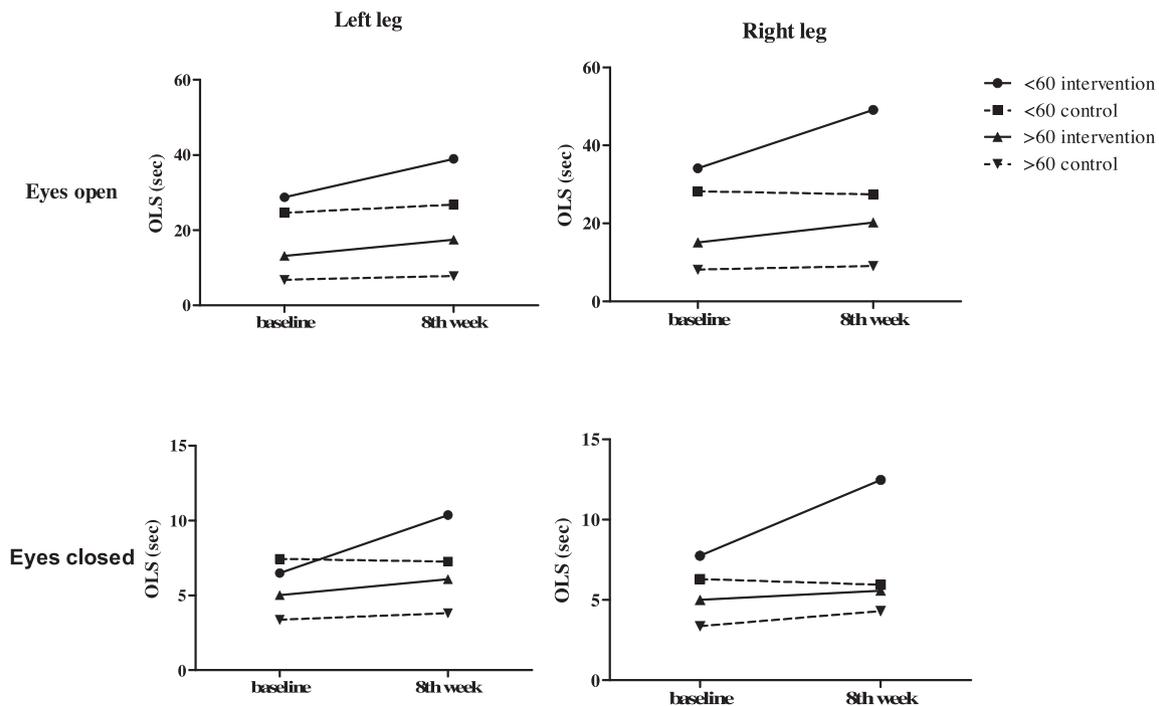


Fig. 1. Mean changes of OLS in eyes open and eyes closed condition of both leg.

the crucial help of Ms. Shivani Verma for her critical editing of English grammar and syntax of the manuscript.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.gaitpost.2019.08.018>.

References

- G. Deli, E. Bosnyak, G. Pusch, S. Komoly, G. Feher, Diabetic neuropathies: diagnosis and management, *Neuroendocrinology* 98 (2013) 267–280.
- D. Ziegler, N. Papanas, A.I. Vinik, J.E. Shaw, Epidemiology of polyneuropathy in diabetes and prediabetes, *Handb. Clin. Neurol.* 126 (2014) 3–22.
- D. Bansal, K. Gudala, H. Muthyala, H.P. Esam, R. Nayakallu, A. Bhansali, Prevalence and risk factors of development of peripheral diabetic neuropathy in type 2 diabetes mellitus in a tertiary care setting, *J. Diabetes Investig.* 5 (6) (2014) 714–721.
- B. Lu, Z. Yang, M. Wang, Z. Yang, W. Gong, Y. Yang, et al., High prevalence of diabetic neuropathy in population-based patients diagnosed with type 2 diabetes in the Shanghai downtown, *Diabetes Res. Clin. Pract.* 88 (3) (2010) 289–294.
- P.K. Rani, R. Raman, S.R. Rachapalli, S. Saumya Pal, V. Kulothungan, T. Sharma, et al., Prevalence and risk factors for severity of diabetic neuropathy in type 2 diabetes mellitus, *Indian J. Med. Sci.* 64 (2) (2010).
- D. Ziegler, W. Rathmann, T. Dickhaus, C. Meisinger, A. Mielck, D. Ziegler, Prevalence of polyneuropathy in prediabetes and diabetes is associated with abdominal obesity and macroangiopathy. The MONICA/KORA augsburg surveys S2 and S3, *Diabetes Care* (2007).
- H. Gill, S. Yadav, V. Ramesh, E. Bhatia, A prospective study of prevalence and association of peripheral neuropathy in Indian patients with newly diagnosed type 2 diabetes mellitus, *J. Postgrad. Med.* 60 (3) (2014) 270.
- E.W. Gregg, P. Sorlie, R. Paulose-ram, M.S. Eberhardt, M. Wolz, V. Burt, et al., Prevalence of lower-extremity disease in the U.S. adult population & 40 years of age with and without diabetes 1999–2000 national health and nutrition examination survey, *Diabetes Care* 27 (7) (2004) 1591–1597.
- J. Gill, J.H.J. Allum, M.G. Carpenter, M. Held-Ziolkowska, A.L. Adkin, F. Honegger, et al., Trunk sway measures of postural stability during clinical balance tests: effects of age, *J. Gerontol. Ser. A Biol. Sci. Med. Sci.* 56 (7) (2001) M438–47.
- L. Vereeck, F. Wuyts, S. Truijen, P. Van De Heyning, Clinical assessment of balance: normative data, and gender and age effects, *Int. J. Audiol.* 47 (2) (2008) 67–75.
- H.B. Menz, S.R. Lord, R. St George, R.C. Fitzpatrick, Walking stability and sensorimotor function in older people with diabetic peripheral neuropathy, *Arch. Phys. Med. Rehabil.* 85 (2) (2004) 245–252.
- A. Cimbiz, O. Cakir, Evaluation of balance and physical fitness in diabetic neuropathic patients, *J. Diabetes Complications* 19 (3) (2005) 160–164.
- M.R. Camargo, J.A. Barela, A.J.L. Nozabieli, A.M. Mantovani, A.R. Martinelli, C.E.P.T. Fregonesi, Balance and ankle muscle strength predict spatiotemporal gait parameters in individuals with diabetic peripheral neuropathy, *Diabetes Metab. Syndr. Clin. Res. Rev.* 9 (2) (2015) 79–84.
- A. Goldberg, J.W. Russell, N.B. Alexander, Standing balance and trunk position sense in impaired glucose tolerance (IGT)-related peripheral neuropathy, *J. Neurol. Sci.* 270 (1–2) (2008) 165–171.
- K.I. Ites, E.J. Anderson, M.L. Cahill, J.A. Kearney, E.C. Post, L.S. Gilchrist, Balance interventions for diabetic peripheral neuropathy: a systematic review, *J. Geriatr. Phys. Ther.* 34 (3) (2011) 109–116.
- F. Streckmann, E.M. Zopf, H.C. Lehmann, K. May, J. Rizza, P. Zimmer, et al., Exercise intervention studies in patients with peripheral neuropathy: a systematic review, *Sport Med.* 44 (9) (2014) 1289–1304.
- I. Ahmad, E. Hussain, D. Singla, S. Verma, K. Ali, Balance training in diabetic peripheral neuropathy: a narrative review, *JSM Diabetol. Manage.* 2 (1) (2017).
- K. Lee, S. Lee, C. Song, Whole-body vibration training improves balance, muscle strength and glycosylated hemoglobin in elderly patients with diabetic neuropathy, *Tohoku J. Exp. Med.* (2012) 305–314.
- C.H. Song, J.S. Petrofsky, S.W. Lee, K.J. Lee, J.E. Yim, Effects of an exercise program on balance and trunk proprioception in older adults with diabetic neuropathies, *Diabetes Technol. Ther.* 13 (8) (2011) 803–811.
- M. Akbari, H. Jafari, A. Moshahae, B. Forough, Do diabetic neuropathy patients benefit from balance training? *J. Rehabil. Res. Dev.* 49 (2) (2012) 333–338.
- L. Allet, S. Armand, R.A. De Bie, A. Golay, D. Monnin, K. Aminian, et al., The gait and balance of patients with diabetes can be improved: a randomised controlled trial, *Diabetologia* 53 (3) (2010) 458–466.
- R.L. Kruse, J.W. LeMaster, R.W. Madsen, Fall and balance outcomes after an intervention to promote leg strength, balance, and walking in people with diabetic peripheral neuropathy: “Feet first” randomized controlled trial, *Phys. Ther.* 90 (11) (2010) 1568–1579.
- J.K. Richardson, D. Sandman, S. Vela, A focused exercise regimen improves clinical measures of balance in patients with peripheral neuropathy, *Arch. Phys. Med. Rehabil.* 82 (2) (2001) 205–209.
- H. Salsabili, F. Bahrpeyma, B. Forough, S. Rajabali, Dynamic stability training improves standing balance control in neuropathic patients with type 2 diabetes, *J. Rehabil. Res. Dev.* 48 (7) (2011) 775.
- S. Wurm, M.J. Tomasik, C. Tesch-Römer, On the importance of a positive view on ageing for physical exercise among middle-aged and older adults: cross-sectional and longitudinal findings, *Psychol. Health* 25 (1) (2010) 25–42.
- P.W. Duncan, D.K. Weiner, J. Chandler, S. Studenski, Functional reach: a new clinical measure of balance, *J. Gerontol.* 45 (6) (1990) M192–M197.
- D. Podsiadlo, S. Richardson, The timed “up & go”: a test of basic functional mobility for frail elderly persons, *J. Am. Geriatr. Soc.* 39 (2) (1991) 142–148.
- R.W. Bohannon, K. Schaubert, Long-term reliability of the timed up-and-go test among community-dwelling elders, *J. Phys. Ther. Sci.* 17 (2) (2005) 93–96.
- M. Lin, H. Hwang, M. Hu, H.I. Wu, Y. Wang, F. Huang, Psychometric comparisons of the timed up and go, one leg stand, functional reach, and Tinetti balance measures in community dwelling older people, *J. Am. Geriatr. Soc.* 52 (8) (2004) 1343–1348.
- D.J. Goble, Proprioceptive acuity assessment via joint position matching: from basic science to general practice, *Phys. Ther.* 90 (8) (2010) 1176–1184.
- P. Jha, I. Ahmad, S. Khurana, A. Kamran, S. Verma, T. Kumar, Proprioception: an evidence based narrative review, *Res. Inves. Sports Med.* 1 (2) (2017) 1–5.
- M.M. Noohu, J.A. Moiz, A.B. Dey, M.E. Hussain, A balance device reliability for reaction time and proprioception measurement in older adults, *Indian J. Gerontol.* 30 (3) (2016) 396–403.
- T.M. Steffen, T.A. Hacker, L. Mollinger, Age-and gender-related test performance in community-dwelling elderly people: Six-Minute Walk Test, Berg Balance Scale, Timed Up & Go Test, and gait speeds, *Phys. Ther.* 82 (2) (2002) 128–137.
- J. Condron, K. Hill, G. Physio, Reliability and validity of a dual-task force platform assessment of balance performance effect of age, balance impairment, and cognitive task, *J. Am. Geriatr. Soc.* 50 (1) (2002) 157–162.
- I. Melzer, N. Benjuya, J. Kaplanski, Postural stability in the elderly: a comparison between fallers and non-fallers, *Age Ageing* 33 (6) (2004) 602–607.
- Y. Lajoie, S. Gallagher, Predicting falls within the elderly community: comparison of postural sway, reaction time, the Berg balance scale and the Activities-specific Balance Confidence (ABC) scale for comparing fallers and non-fallers, *Arch. Gerontol. Geriatr.* 38 (1) (2004) 11–26.
- A.I. Adler, E.J. Boyko, J.H. Ahroni, V. Stensel, R.C. Forsberg, D.G. Smith, Risk factors for diabetic peripheral sensory neuropathy. Results of the Seattle Prospective Diabetic Foot Study, *Diabetes Care* 20 (7) (1997) 1162–1167.
- S. Tesfaye, L.K. Stevens, J.M. Stephenson, J.H. Fuller, M. Plater, C. Ionescu-Tirgoviste, et al., Prevalence of diabetic peripheral neuropathy and its relation to glycaemic control and potential risk factors: the EURODIAB IDDM Complications Study, *Diabetologia* 39 (11) (1996) 1377–1384.
- R.T. Crews, S.V. Yalla, A.E. Fleischer, S.C. Wu, A growing troubling triad: diabetes, aging, and falls, *J. Aging Res.* 2013 (2013).
- J.K. Richardson, E.A. Hurvitz, Peripheral neuropathy: a true risk factor for falls, *J. Gerontol. Ser. A Biol. Sci. Med. Sci.* 50A (4) (1995) M211–5.
- E. Murray, J. Burns, S.S. Tai, R. Lai, I. Nazareth, Interactive Health Communication Applications for people with chronic disease, *Cochrane Database Syst. Rev.* (4) (2005).
- T.E. Prieto, J.B. Myklebust, R.G. Hoffmann, E.G. Lovett, B.M. Myklebust, Measures of postural steadiness differences between healthy young and elderly adults, *IEEE Trans. Inf. Technol. Biomed.* 43 (9) (1996) 965–966.
- M.G. Carpenter, A.L. Adkin, L.R. Brawley, J.S. Frank, Postural, physiological and psychological reactions to challenging balance: Does age make a difference? *Age Ageing* 35 (3) (2006) 298–303.
- D.R. Toledo, J.A. Barela, Sensory and motor differences between young and older adults: somatosensory contribution to postural control, *Br. J. Phys. Ther.* 14 (3) (2010) 267–275.
- A.L. Adkin, J.S. Frank, M.G. Carpenter, G.W. Peysar, Postural control is scaled to level of postural threat, *Gait Posture* 12 (2) (2000) 87–93.
- M. Carpenter, J. Frank, C. Silcher, G. Peysar, The influence of postural threat on the control of upright stance, *Exp. Brain Res.* 138 (2) (2001) 210–218.
- K. Delbaere, D.L. Sturnieles, G. Crombez, S.R. Lord, Concern about falls elicits changes in gait parameters in conditions of postural threat in older people, *J. Gerontol. Ser. A Biol. Sci. Med. Sci.* 64A (2) (2009) 237–242.
- Z. Rohjani-Shirazi, F. Barzintaj, M.R. Salimifard, Comparison the effects of two types of therapeutic exercises Frenkele vs. Swiss ball on the clinical balance measures in patients with type II diabetic neuropathy, *Diabetes Metab. Syndr. Clin. Res. Rev.* 11 (2016) S29–32.
- S. Morrison, S.R. Colberg, H.K. Parson, A.I. Vinik, Exercise improves gait, reaction time and postural stability in older adults with type 2 diabetes and neuropathy, *J. Diabetes Complications* 28 (5) (2014) 715–722.
- G.S. Grewal, M. Schwenk, J. Lee-Eng, S. Parvaneh, M. Bharara, R.A. Menzies, et al., Sensor-based interactive balance training with visual joint movement feedback for improving postural stability in diabetics with peripheral neuropathy: a randomized controlled trial, *Gerontology* 61 (6) (2015) 567–574.
- P. Silva, P.F. Figueredo Borges Botelho, E.C. de Oliveira Guirro, M.M.O.L.L. Vaz, D.C.C. de Abreu, Long-term benefits of somatosensory training to improve balance of elderly with diabetes mellitus, *J. Bodyw. Mov. Ther.* 19 (3) (2015) 453–457.