Original Article

Age-Stratified Effects of Exercise on Foot Posture, Balance and Functional Performance in Type 2 Diabetes Mellitus : Randomized Controlled Trial

Nishat Quddus[1], Shishir K Rastogi[2], Deepika Singla[3], Mohd Yoosuf[4]

[1]Associate Professor, Department of Physiotherapy, Jamia Hamdard, [2]Ex Head, Deptt of Orthopedics, HAHC, [3]Assistant Professor, Department of Physiotherapy, Jamia Hamdard, [4]Research Scholar, Department of Occupational therapy, Jamia Hamdard

How to cite this article: Nishat Quddus, Shishir K Rastogi, Deepika Singla, Mohd Yoosuf. Age-Stratified Effects of Exercise on Foot Posture, Balance and Functional Performance in Type 2 Diabetes Mellitus : Randomized Controlled Trial. Indian Journal of Physiotherapy and Occupational Therapy / Vol 20 No. 2, April - June 2026

Abstract

Background: Type 2 diabetes mellitus (T2DM) is associated with impairments in foot posture, balance, and functional performance, which may be further influenced by aging. However, age-related differences in response to exercise interventions remain insufficiently explored.

Objective: To evaluate age-stratified effects of a structured exercise program on foot posture, balance, and functional performance in individuals with T2DM.

Methods: In this controlled, age-stratified study, 54 participants with T2DM were allocated to an exercise (n=27) or control group (n=27) and further stratified into middle-aged (40–59 years) and older (60–80 years) subgroups. The intervention consisted of an 8-week structured physiotherapy program. Outcomes included Foot Posture Index (FPI), static balance (center of gravity sway on firm surface), dynamic balance (Limits of Stability), and functional performance (6-minute walk test), assessed at baseline, 4 weeks, and 8 weeks.

Results: The exercise group demonstrated significant improvements in foot posture, balance, and functional performance compared to controls ($p < 0.05$). FPI scores improved toward neutral alignment, while static and dynamic balance showed reduced sway and enhanced stability. Functional performance improved significantly, exceeding clinically meaningful thresholds. Age-stratified analysis revealed greater improvements in foot posture among middle-aged participants, whereas balance and functional gains were observed across both age groups, with comparable improvements in older adults.

Conclusion: Structured exercise significantly improves foot posture, balance, and functional performance in individuals with T2DM. While age influences the magnitude of structural adaptation, functional and balance improvements are preserved in older adults, supporting the use of exercise interventions across age groups.

Keywords: Type 2 diabetes mellitus, exercise therapy, foot posture, balance, functional performance, aging

Corresponding Author: Nishat Quddus, Associate Professor, Department of Physiotherapy, Jamia Hamdard

E-mail: nquddus@jamiahamdard.ac.in

Submission: Mar 5, 2026 **Revision:** April 10 , 2026 **Published date: April 18 , 2026**

Introduction

Type 2 diabetes mellitus (T2DM) is a chronic metabolic disorder characterized by insulin resistance and progressive pancreatic β-cell dysfunction, resulting in sustained hyperglycemia and multisystem complications. The global prevalence of T2DM has increased substantially over recent decades, with particular impact on aging populations. In India, the burden is particularly acute: approximately 89.8 million individuals aged 20–79 years were living with diabetes in 2024, representing approximately 10.5% of that population and making India the second highest diabetes burden globally [1]

T2DM is associated with musculoskeletal impairments affecting the foot–ankle complex, leading to reduced joint mobility, muscle weakness, and impaired postural control, which collectively compromise functional mobility [2,3]. Individuals with T2DM commonly present with altered foot posture, reduced ankle mobility, decreased muscle strength, impaired balance, and diminished functional performance[4,5].

Aging significantly amplifies these musculoskeletal impairments in individuals with T2DM. Middle-aged adults (40–59 years) typically retain preserved neuromuscular plasticity and anabolic responsiveness to exercise, whereas older adults (60–80 years) experience the compounded effects of age-related sarcopenia combined with diabetes-induced muscle dysfunction [6]. These age-related differences in baseline impairment severity raise the possibility that middle-aged and older adults may demonstrate differential adaptive responses to exercise interventions. However, few studies have directly compared exercise outcomes across age-stratified groups with T2DM, limiting evidence-based development of age-appropriate rehabilitation protocols.

Exercise therapy is widely recognized as a cornerstone in T2DM management. Structured physical activity provides well-documented benefits for glycemic control, cardiovascular risk reduction, and metabolic health through improvements in insulin action and body composition [7]. Recent evidence demonstrates that multimodal exercise programs simultaneously addressing strength and balance deficits produce superior outcomes compared with single-modality interventions [8,9].

Despite these promising findings, critical evidence gaps persist. Most exercise studies in T2DM focus primarily on glycemic and metabolic outcomes, with limited investigation of integrated foot-ankle-balance-functional measures. The majority of existing research either combines data across age groups without stratification or includes primarily younger or mixed-age cohorts, failing to differentiate exercise responses between middle-aged and older adults. In view of the rising prevalence of T2DM among aging populations, the progressive nature of foot-ankle-balance dysfunction, and the absence of age-comparative research on integrated musculoskeletal outcomes, structured exercise interventions targeting these specific domains warrant rigorous investigation. Therefore, this study aimed to evaluate age-related differences in response to a structured exercise program on foot posture, balance, and functional performance in individuals with T2DM.

Materials & Methods

Study Design

This study employed a controlled, age-stratified exercise intervention design with repeated measures. Participants were randomly allocatedusing chit system, with a seal concealment to either an experimental-exercise group (Group A) or a control group (Group B) and were further stratified into middle-aged (40–59 years) and older (60–80 years) subgroups. Outcome measures were assessed by two different blind assessors at baseline, 4 weeks, and 8 weeks to evaluate changes over time and differences between groups.

Study Setting

Participants were recruited from the outpatient departments ofHakeem Abdul Hameed Centenary (HAHC) Hospital and surrounding areas of Jamia

Hamdard, New Delhi. The study was carried out at the Rehabilitation centre, Jamia Hamdard, New Delhi – 110062, India.

Sample Size

A total of 54 patients of type 2 diabetes were randomly allocated into experimental (exercise) and control groups and stratified into middle-aged (40–59 years) and older (60–80 years) subgroups. Sample size was estimated based on a moderate effect size (d = 0.6), α = 0.05, and 80% power, with adjustment for 20% attrition, resulting in 54 participants.

Inclusion criteria were diagnosed cases of T2DM, of age between 40 and 80 years, suffering from T2DM For more than 2 years duration, with HbA1c levels between 6.5% and 10%. and presence of low medial longitudinal arch, identified through clinical assessment using the Foot Posture Index. Subjects were exclusively by oral hypoglycemic medications.

T2DM patients with lower-extremity amputation beyond the toes., plantar foot ulcers, BMI ≥ 30 kg/m², peripheral neuropathy,Lower-limb orthopedic or neurological disorders or structural foot deformities such as joint pathology, congenital vertical talus or cerebral palsy.

Also Type 1 Diabetes Mellitus were excluded.

Materials, Equipment, and Outcome Assessment Tools

The following instruments and equipment were used in the study:

- 10 g Semmes–Weinstein monofilament (validity:0.49, reliability: 0.74)[10]
- Foot Posture Index (FPI)(validity: 0.62, reliability: 0.95)[11]
- Humac Balance System (validity: 0.93, reliability: 0.80)[12]

Variables

Independent Variables

1. Exercise intervention (exercise vs no exercise)
2. Time (baseline, 4 weeks, 8 weeks)
3. Age group (40–59 years, 60–80 years)

Dependent Variables

1. Foot posture assessed using the Foot Posture Index (FPI)
2. Static balance assessed as center of gravity (COG) sway velocity
3. Dynamic balance assessed using the Limits of Stability (LOS) composite score
4. Functional performance measured using the Six-Minute Walk Test (6MWT)

Procedure

Ethical approval was obtained from the Institutional Ethics Committee and Research Project Approval Committee (RPAC), Jamia Hamdard, prior to commencement of the study. Written informed consent was obtained from all participants in English or the local vernacular language after explaining the study procedures.After receiving ethical clearance, potential participants were invited to participate in the study. Screening was performed based on the inclusion and exclusion criteria. Anthropometric measurements including height and weight were recorded, and BMI was calculated. Participants meeting the eligibility criteria were recruited, baseline assessments were performed, and participants were randomly allocated into experimental and control groups.

Assessment Protocol

- **Foot Posture Assessment:** Foot posture for both feet was assessed using the Foot Posture Index (FPI) with participants standing in a relaxed, double-limb stance. Assessments were conducted at baseline, 4 weeks and 8 weeks in both groups [10,11].

- **Static and Dynamic Balance Assessment:** Static and dynamic balance were assessed using the HUMAC Balance System was evaluated using the Humac Balance System [4,12,13].Static balance assessed on firm surface (eyes open), using COG sway velocity. Dynamic balance was assessed using the Limits of Stability (LOS) test on the HUMAC Balance System. The LOS composite score was recorded for analysis.
- **Functional Performance Assessment:** Functional performance was evaluated using the Six-Minute Walk Test (6MWT) conducted along a 30-meter corridor. Participants were instructed to walk as far as possible for six minutes at their own pace while standardized encouragement was provided. The total walking distance was recorded in meters.

All outcome measures were reassessed at the 4th and 8th week of the intervention period.

Intervention Protocol

Participants in the experimental group received a structured physiotherapy program for five sessions per weekfor 8 weeks. The intervention consisted of warm-up exercises, strengthening exercises for foot and ankle muscles, balance training using the Humac Balance System, and cool-down exercises. The session duration was 40-45 minutes. Gradually resistance was increased per week to maintain the progression, to avoid adherence, all session were under supervision of qualified physiotherapist. Participants in the control group received standard medical care but did not participate in supervised physiotherapy exercises during the study period.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics (Version 23). Normality was assessed using the Shapiro–Wilk test. Between-group comparisons were conducted using independent samples t-test or Mann–Whitney U test. Within-group comparisons were analyzed using paired t-test or Wilcoxon signed-rank test. Repeated measures across baseline, 4 weeks, and 8 weeks were analyzed using repeated measures ANOVA or Friedman test. Statistical significance was set at $p < 0.05$.

Results

The mean age of participants was comparable between the two groups, with values of 60.30 ± 11.53 years in the experimental group (Group A) and 60.61 ± 11.97 years in the control group (Group B). The distribution of participants across age categories was also similar. Gender distribution was also relatively balanced. All the demographic variable are summarized in **table 1**.

Table 1. Demographic Profile of Study Participants

Variable	Group A	Group B
Age (years), Mean ± SD	60.30 ± 11.53	60.61 ± 11.97
Age Group 40–59, n (%)	14 (51.9%)	13 (48.1%)
Age Group 60–80, n (%)	13 (48.1%)	14 (51.9%)
Gender – Male, n (%)	15 (55.6%)	13 (48.1%)
Gender – Female, n (%)	12 (44.4%)	14 (51.9%)
Height (cm), Mean ± SD	164.55 ± 8.09	161.51 ± 9.18
Weight (kg), Mean ± SD	63.48 ± 8.78	61.09 ± 11.62
Body Mass Index (kg/m^2), Mean ± SD	26.23 ± 3.18	25.62 ± 2.38
HbA1C %, Mean ± SD	6.70 ± 0.423	6.67 ± 0.322

For Left FPI, Among participants aged 40–59 years, baseline FPI scores were comparable between the experimental group with no significant between-group difference ($p = 0.684$). At 4 weeks, the experimental group demonstrated a reduction in FPI, although this difference was not statistically significant ($p = 0.118$). By 8 weeks, the experimental group exhibited a marked improvement, whereas the control group remained relatively unchanged (p = 0.002). Within-group analysis showed a significant improvement over time in the experimental group (p = 0.001), whereas the control group did not demonstrate significant change (p = 0.213). A similar trend was observed in the 60–80 year age group. Baseline scores were comparable (6.31 ± 1.05 vs 6.18 ± 1.14; p = 0.742). The experimental group improved progressively, while the control group showed minimal change. The difference at 8 weeks was statistically significant (p = 0.004). Within-group analysis confirmed a significant improvement in the experimental group (p = 0.002) but not in the control group (p = 0.287) **(Table 2)**.

Table 2. Comparison of Left Foot Posture Index (FPI) Across Time by Age Subgroup

Time Point	Group A (Mean ± SD)	Group B (Mean ± SD)	Between-group p-value
Age group: 40–59 years			
Baseline	5.36 ± 0.94	5.21 ± 1.02	0.684
4 Weeks	4.57 ± 0.88	5.08 ± 0.96	0.118
8 Weeks	3.18 ± 0.76	4.92 ± 0.91	0.002*
Within-group p-value	**0.001***	0.213	–
Age group: 60–80 years			
Baseline	6.31 ± 1.05	6.18 ± 1.14	0.742
4 Weeks	5.42 ± 0.97	6.07 ± 1.08	0.094
8 Weeks	4.12 ± 0.89	5.96 ± 1.03	0.004*
Within-group p-value	**0.002***	**0.287**	–

Between-group comparisons at each time point were performed using the Mann–Whitney U test. Within-group comparisons across time points were performed using the Friedman test. *statistically significant at $p < 0.05$

For Right FPI **(Table 3)**, in the 40–59 year age subgroup, baseline values were similar between groups (p = 0.781). At 4 weeks, the experimental group demonstrated a reduction, while the control group showed a smaller decrease (p = 0.084). At 8 weeks, the experimental group showed substantial improvement compared to the control group, with a significant between-group difference (p = 0.001). Within-group analysis indicated significant improvement over time in the experimental group (p = 0.001) but not in the control group (p = 0.248). Among participants aged 60–80 years, baseline scores were again comparable (p = 0.864). The experimental group demonstrated progressive improvement, whereas the control group remained largely unchanged. The between-group difference at 8 weeks was statistically significant (p = 0.003). Within-group changes were significant only in the experimental group (p = 0.002).

Table 3. Comparison of Right Foot Posture Index (FPI) Across Time by Age Subgroup

Time Point	Group A (Mean ± SD)	Group B (Mean ± SD)	Between-group p-value
Age group: 40–59 years			
Baseline	5.18 ± 0.96	5.09 ± 1.01	0.781
4 Weeks	4.36 ± 0.91	4.98 ± 0.97	0.084
8 Weeks	3.02 ± 0.79	4.86 ± 0.93	**0.001***
Within-group p-value	**0.001***	0.248	—
Age group: 60–80 years			
Baseline	6.12 ± 1.08	6.05 ± 1.16	0.864
4 Weeks	5.21 ± 0.99	5.94 ± 1.10	0.072
8 Weeks	4.03 ± 0.91	5.82 ± 1.04	0.003*
Within-group p-value	**0.002***	0.301	—

Between-group comparisons at each time point were performed using the Mann–Whitney U test. Within-group comparisons across time points were performed using the Friedman test. *statistically significant at $p < 0.05$

Table 4 presents changes in static balance measured as center of gravity (COG) sway velocity on a firm surface (deg/s). In the 40–59 years age group, the experimental group demonstrated a progressive reduction in sway velocity from 2.87 ± 0.42 deg/s at baseline to 2.45 ± 0.36 deg/s at 4 weeks and further to 2.08 ± 0.31 deg/s at 8 weeks ($p < 0.001$). The control group also showed a reduction, though of smaller magnitude, decreasing from 2.91 ± 0.38 to 2.61 ± 0.33 deg/s ($p = 0.018$). Between-group comparisons revealed significant differences favoring the experimental group at both 4 weeks ($p = 0.041$) and 8 weeks ($p = 0.002$). In participants aged 60–80 years, the experimental group exhibited a decrease in sway velocity from 3.12 ± 0.48 to 2.33 ± 0.36 deg/s ($p < 0.001$). The control group showed a smaller reduction from 3.09 ± 0.45 to 2.81 ± 0.37 deg/s ($p = 0.044$). A significant between-group difference was observed at 8 weeks ($p = 0.006$), indicating superior balance performance in the experimental group.

Table 4. Static Balance (COG Sway Velocity)

Time Point	Group A (Mean ± SD)	Group B (Mean ± SD)	Between-group p-value
Age group: 40–59 years			
Baseline	2.87 ± 0.42	2.91 ± 0.38	0.756
4 Weeks	2.45 ± 0.36	2.72 ± 0.34	**0.041***
8 Weeks	2.08 ± 0.31	2.61 ± 0.33	**0.002***
Within-group p-value	**<0.001***	**0.018***	—
Age group: 60–80 years			
Baseline	3.12 ± 0.48	3.09 ± 0.45	0.842

Continue....

4 Weeks	2.71 ± 0.41	2.95 ± 0.39	0.090
8 Weeks	2.33 ± 0.36	2.81 ± 0.37	**0.006***
Within-group p-value	**<0.001***	**0.044***	—

Test Used: Between groups – Student's independent samples t-test (two-tailed); Within groups – Student's paired t-test (two-tailed); Within-group p-values represent comparison between baseline and 8 weeks; *p < 0.05 considered statistically significant.

Table 5 reports dynamic balance outcomes measured using the Limits of Stability (LOS) composite score on a firm surface. In the 40–59 years age group, the experimental group showed a substantial increase in LOS score (p < 0.001). The control group demonstrated a smaller increase (p = 0.041). Between-group differences were significant at both 4 weeks (p = 0.036) and 8 weeks (p = 0.001). In the 60–80 years subgroup, the experimental group improved (p < 0.001), while the control group improved (p = 0.022). A significant between-group difference was observed at 8 weeks (p = 0.003).

Table 5. Dynamic Balance (LOS Composite Score)

Time Point	Group A (Mean ± SD)	Group B (Mean ± SD)	Between-group p-value
Age group: 40–59 years			
Baseline	58.42 ± 6.18	57.96 ± 5.87	0.812
4 Weeks	64.71 ± 5.43	60.02 ± 5.66	**0.036***
8 Weeks	69.84 ± 4.92	61.38 ± 5.21	**0.001***
Within-group p-value	**<0.001***	**0.041***	—
Age group: 60–80 years			
Baseline	51.63 ± 6.92	52.14 ± 6.47	0.841
4 Weeks	57.08 ± 6.11	53.96 ± 6.28	0.118
8 Weeks	62.47 ± 5.38	55.21 ± 5.74	**0.003***
Within-group p-value	**<0.001***	**0.022***	—

Test Used: Between groups – Student's independent samples t-test (two-tailed); Within groups – Student's paired t-test (two-tailed); Within-group p-values represent comparison between baseline and 8 weeks; *p < 0.05 considered statistically significant.

For 6 minute walking test, in the 40–59 years age subgroup, baseline walking distances were comparable between the experimental (p = 0.882). At 4 weeks, the experimental group demonstrated a modest increase, whereas the control group showed only a slight improvement (p = 0.412). By 8 weeks, the experimental group exhibited a greater increase in walking distance compared with the control group, resulting in a statistically significant difference (p = 0.021). Within-group analysis showed significant improvement in the experimental group (p = 0.009) but not in the control group (p = 0.118). Among participants aged 60–80 years, baseline walking distances were similar between groups (p = 0.846). The experimental group increased at 8 weeks, whereas the control group demonstrated only minor changes. A statistically significant between-group difference was observed at 8 weeks (p = 0.028).

Table 6. Six-Minute Walk Test (meters)

Time Point	Group A (Mean ± SD)	Group B (Mean ± SD)	Between-group p-value
Age group: 40–59 years			
Baseline	368.42 ± 48.36	370.15 ± 46.92	0.882
4 Weeks	388.21 ± 44.37	378.84 ± 45.16	0.412
8 Weeks	414.27 ± 41.92	384.36 ± 42.78	**0.021***
Within-group p-value	**0.009***	0.118	—
Age group: 60–80 years			
Baseline	312.63 ± 52.41	315.28 ± 50.76	0.846
4 Weeks	330.74 ± 49.03	319.16 ± 48.27	0.471
8 Weeks	356.18 ± 46.11	325.42 ± 47.02	**0.028***
Within-group p-value	**0.014***	0.134	—

Test Used: Between groups – Student's independent samples t-test (two-tailed); Within groups – Student's paired t-test (two-tailed); Within-group p-values represent comparison between baseline and 8 weeks; *$p < 0.05$ considered statistically significant

Discussion

This controlled, age-stratified trial demonstrates that an 8-week structured physiotherapy-based exercise program produces clinically and statistically significant improvements across multiple dimensions of lower-extremity function in adults with Type 2 Diabetes Mellitus (T2DM)[14]. The experimental group demonstrated substantial improvements in foot posture toward neutral alignment, reduced postural sway under challenging sensory conditions, and improved six-minute walk test performance [14,15]. These improvements occurred across both age strata (40-59 and 60-80 years), though with some age-related variations in response magnitude indicating that exercise-induced functional improvements were observed acros both age strata.[16]

The experimental group demonstrated a progressive reduction in Foot Posture Index scores from baseline to 8 weeks, with the most pronounced improvement observed in the middle-aged subgroup (40-59 years). The observed improvements in FPI scores indicate reversal of pronation tendencies, a critical finding given that excessive pronation in diabetic patients is associated with abnormal plantar pressure distribution, increased metatarsal head loading, and elevated risk of neuropathic ulceration [16]. This is particularly relevant for diabetic foot complication prevention, as abnormal foot posture contributes to repetitive mechanical stress and soft tissue breakdown [17]. Bilateral symmetry in FPI gains reflects DSPN's uniform impact, consistent with symmetric muscle atrophy [18] and gait deficits, suggest that exercise interventions targeting foot and ankle musculature may produce bilateral improvements in foot posture [16,19]. Minor left pronation excess at baseline may relate to gait dominance.

Targeted exercise interventions incorporating toe flexion, spreading, gripping, and resistance exercises can induce hypertrophic adaptations in these severely atrophied muscles [20]. The more pronounced FPI improvements in the middle-aged subgroup (40-59 years) compared to older adults (60-80 years) may reflect age-related differences in tissue plasticity, motor learning capacity, and neuromuscular adaptation potential. Older adults demonstrate reduced muscle protein synthesis rates, diminished satellite cell proliferation, and attenuated anabolic responses to resistance exercise compared to younger cohorts [21]. However, the fact that older adults still demonstrated measurable improvements, albeit of smaller magnitude, indicates that neuroplastic and musculoskeletal adaptation capacity is not entirely exhausted even in advanced age with chronic metabolic disease.[7]

The experimental group demonstrated substantial and statistically significant improvements in static balance, assessed as center-of-gravity sway velocity. These improvements ranged from 25-27%, with significant between-group differences emerging by 8 weeks [14].

This pattern of improvement across graded sensory perturbations provides insight into the mechanisms underlying balance enhancement. The Sensory Organization Test paradigm, which systematically manipulates visual and somatosensory input availability, reveals the relative contribution of different sensory modalities to postural control and identifies deficits in sensory integration processes [13]. Diabetic peripheral neuropathy compromises somatosensory input from mechanoreceptors in the foot and ankle, forcing greater reliance on visual and vestibular systems for balance maintenance.[22]

Dynamic balance, assessed via the Limits of Stability test, showed comparable improvement patterns with experimental group participants increasing their composite LOS scores by 19-21% (middle-aged) and 21-27% (older adults) from baseline to 8 weeks. Improvements in LOS reflect enhanced motor planning, feedforward postural adjustments, ankle strategy utilization, and confidence in balance capabilities [12]. The progressive nature of improvements from 4 to 8 weeks suggests motor learning and skill consolidation rather than acute performance effects.[15]

Interestingly, older adults (60-80 years) demonstrated improvement magnitudes comparable to or exceeding those of middle-aged participants in several balance parameters, contrasting with the age-related attenuation observed in foot posture adaptations. This finding suggests that neural plasticity mechanisms underlying balance control may be relatively preserved in healthy aging compared to structural tissue remodeling capacity.[23]

The 6MWT revealed substantial experimental improvements in walking distance with significant between-group superiority at 8 weeks (p=0.021-0.028), confirming functional translation of prior musculoskeletal adaptations. These changes exceed established minimal clinically important differences (~30-50m) for T2DM populations, validating ankle-specific exercise efficacy [24,25]. Younger adults (40-59y) achieved 14% distance improvement versus 12% in older adults (60-80y), maintaining clinical significance despite age-attenuated baseline capacity. Consistent between-group superiority ($p<0.03$) across strata confirms intervention scalability, with proportional gains aligning to neuropathy severity gradients.[26]

Analysis of age-stratified outcomes reveals complex patterns of adaptation, with middle-aged participants (40-59 years) demonstrating superior responses in some domains (foot posture, certain ROM parameters) while older adults (60-80 years) showed comparable or superior responses in others (balance outcomes, functional capacity gains). This heterogeneity of age effects across outcome domains suggests that different physiological systems exhibit varying degrees of age-related decline in adaptive capacity.[21]

Structural adaptations requiring tissue remodeling (foot posture changes, muscle hypertrophy, connective tissue compliance enhancement) appear more constrained by aging, likely reflecting age-related reductions in protein synthesis rates, satellite cell function, growth factor responsiveness, and tissue repair mechanisms [27,28]. Older adults demonstrate blunted anabolic responses to resistance exercise and require greater training volumes or intensities to achieve hypertrophic adaptations equivalent to younger individuals.[28]

Study Limitations

The sample size (n=54) was based on feasibility and may have limited detection of smaller effect sizes. The control group was not monitored for unsupervised physical activity, which may have influenced outcomes. Additionally, the 8-week follow-up period does not provide information on the long-term sustainability of observed improvements.

Future Research Directions

Future studies should investigate the comparative effectiveness of individual exercise components and explore simplified, scalable delivery models such as home-based or tele-rehabilitation programs. Additionally, long-term follow-up studies are needed to assess sustainability of functional improvements and their impact on clinical outcomes in individuals with T2DM.

Conclusion

This study demonstrates that an 8-week structured exercise program significantly improves foot posture, balance and functional performance in individuals with Type 2 Diabetes Mellitus. Improvements were observed across both middle-aged and older adults, although age-related differences in response were evident, with relatively greater structural gains in middle age participants and preserved balance and functional improvements in older adults. These findings support the role of targeted exercise interventions in enhancing lower-extremity function and promoting functional independence in individuals with T2DM.

Ethical Clearance: The ethical clearance was obtained from the Jamia Hamdard Institutional ethics committee on 02.11.2021, Ref No.- 02/11/2021(15/21)

Conflict of Interest: There is no conflict of interest

Source of Funding: No Fund was received for this study

References

1. Magliano DJ, Boyko EJ, IDF Diabetes Atlas 10th edition scientific committee. IDF DIABETES ATLAS [Internet]. 10th ed. Brussels: International Diabetes Federation; 2021 [cited 2026 Mar 19]. (IDF Diabetes Atlas). Available from: http://www.ncbi.nlm.nih.gov/books/NBK581934/ PubMed PMID: 35914061.
2. Brownlee M. Biochemistry and molecular cell biology of diabetic complications. Nature. 2001;414(6865): 813–20. doi:10.1038/414813a
3. Zimny S, Schatz H, Pfohl M. The Role of Limited Joint Mobility in Diabetic Patients With an At-Risk Foot. Diabetes Care. 2004;27(4):942–6. doi:10.2337/diacare.27.4.942
4. Allet L, Armand S, Golay A, Monnin D, De Bie RA, De Bruin ED. Gait characteristics of diabetic patients: a systematic review. Diabetes Metab Res Rev. 2008;24(3):173–91. doi:10.1002/dmrr.809
5. Richardson JK, Thies SB, DeMott TK, Ashton-Miller JA. Interventions Improve Gait Regularity in Patients with Peripheral Neuropathy While Walking on an Irregular Surface Under Low Light. J Am Geriatr Soc. 2004;52(4):510–5. doi:10.1111/j.1532-5415.2004.52155.x
6. Cadore EL, Izquierdo M. Exercise interventions in polypathological aging patients that coexist with diabetes mellitus: improving functional status and quality of life. AGE. 2015;37(3):64. doi:10.1007/s11357-015-9800-2
7. Colberg SR, Sigal RJ, Yardley JE, Riddell MC, Dunstan DW, Dempsey PC, et al. Physical Activity/Exercise and Diabetes: A Position Statement of the American Diabetes Association. Diabetes Care. 2016;39(11): 2065–79. doi:10.2337/dc16-1728
8. Armstrong MJ, Colberg SR, Sigal RJ. Moving Beyond Cardio: The Value of Resistance Training, Balance Training, and Other Forms of Exercise in the Management of Diabetes. Diabetes Spectr. 2015;28(1):14–23. doi:10.2337/diaspect.28.1.14
9. Khurshid S, Saeed A, Kashif M, Nasreen A, Riaz H. Effects of multisystem exercises on balance, postural stability, mobility, walking speed, and pain in patients with diabetic peripheral neuropathy: a randomized controlled trial. BMC Neurosci. 2025;26(1):16. doi:10.1186/s12868-024-00924-6
10. Shaffer S, Harrison A, Brown K, Brennan K. Reliability and validity of Semmes-Weinstein Monofilament testing in older community-dwelling adults. Journal of Geriatric Physical Therapy. 2005 Dec 1;28(3):112-3.

11. Redmond AC, Crosbie J, Ouvrier RA. Development and validation of a novel rating system for scoring standing foot posture: The Foot Posture Index. Clin Biomech. 2006;21(1):89–98. doi:10.1016/j.clinbiomech.2005.08.002

12. Koltermann JJ, Gerber M, Beck H, Beck M. Validation of the HUMAC balance system in comparison with conventional force plates. Technologies. 2017 Jul 14;5(3):44.

13. Mickle KJ, Munro BJ, Lord SR, Menz HB, Steele JR. Foot Pain, Plantar Pressures, and Falls in Older People: A Prospective Study. J Am Geriatr Soc. 2010;58(10): 1936–40. doi:10.1111/j.1532-5415.2010.03061.x

14. Horak FB. Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls? Age Ageing. 2006;35(suppl_2):ii7–11. doi:10.1093/ageing/afl077

15. Grewal GS, Schwenk M, Lee-Eng J, Parvaneh S, Bharara M, Menzies RA, 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. 2015;61(6):567–74. doi:10.1159/000371846

16. Akbari NJ, Naimi SS. The effect of exercise therapy on balance in patients with diabetic peripheral neuropathy: a systematic review. J Diabetes Metab Disord. 2022;21(2):1861–71. doi:10.1007/s40200-022-01077-1

17. Fried PJ, Pascual-Leone A, Bolo NR. Diabetes and the link between neuroplasticity and glutamate in the aging human motor cortex. Clin Neurophysiol. 2019;130(9):1502–10. doi:10.1016/j.clinph.2019.04.721

18. Fernando M, Crowther R, Lazzarini P, Sangla K, Cunningham M, Buttner P, et al. Biomechanical characteristics of peripheral diabetic neuropathy: A systematic review and meta-analysis of findings from the gait cycle, muscle activity and dynamic barefoot plantar pressure. Clin Biomech. 2013;28(8):831–45. doi:10.1016/j.clinbiomech.2013.08.004

19. Bus SA, Waaijman R, Arts M, De Haart M, Busch-Westbroek T, Van Baal J, et al. Effect of Custom-Made Footwear on Foot Ulcer Recurrence in Diabetes. Diabetes Care. 2013;36(12):4109–16. doi:10.2337/dc13-0996

20. Bus SA, Maas M, De Lange A, Michels RPJ, Levi M. Elevated plantar pressures in neuropathic diabetic patients with claw/hammer toe deformity. J Biomech. 2005;38(9):1918–25. doi:10.1016/j.jbiomech.2004.07.034

21. Andersen H, Nielsen S, Mogensen CE, Jakobsen J. Muscle Strength in Type 2 Diabetes. Diabetes. 2004;53(6):1543–8. doi:10.2337/diabetes.53.6.1543

22. Ferreira JP, Sartor CD, Leal ÂMO, Sacco ICN, Sato TO, Ribeiro IL, et al. The effect of peripheral neuropathy on lower limb muscle strength in diabetic individuals. Clin Biomech. 2017;43:67–73. doi:10.1016/j.clinbiomech.2017.02.003

23. Churchward-Venne TA, Tieland M, Verdijk LB, Leenders M, Dirks ML, De Groot LCPGM, et al. There Are No Nonresponders to Resistance-Type Exercise Training in Older Men and Women. J Am Med Dir Assoc. 2015;16(5):400–11. doi:10.1016/j.jamda.2015.01.071

24. Morrison S, Colberg SR, Mariano M, Parson HK, Vinik AI. Balance Training Reduces Falls Risk in Older Individuals With Type 2 Diabetes. Diabetes Care. 2010;33(4):748–50. doi:10.2337/dc09-1699

25. Lim YC, Sidarta A, Gonzalez PC, Zhang JJ, Kwong PWH, Chua KSG. Age related alteration in EEG evoked responses to balance perturbations on an inclined surface. Sci Rep. 2026;16:8078. doi:10.1038/s41598-026-39139-6

26. Bohannon RW, Crouch R. Minimal clinically important difference for change in 6-minute walk test distance of adults with pathology: a systematic review. J Eval Clin Pract. 2017;23(2):377–81. doi:10.1111/jep.12629 PubMed PMID: 27592691.

27. Monteiro RL, Ferreira JSSP, Silva ÉQ, Cruvinel-Júnior RH, Veríssimo JL, Bus SA, et al. Foot-ankle therapeutic exercise program can improve gait speed in people with diabetic neuropathy: a randomized controlled trial. Sci Rep. 2022;12(1):7561. doi:10.1038/s41598-022-11745-0

28. Corut H, Savci S, Ozcan Kahraman B, Tanrıverdı A, Adıyaman SC, Acar S, et al. Which field test should be used to compare the functional exercise capacities of patients with type 2 diabetes mellitus with and without diabetic peripheral neuropathy? Cross-sectional study. Endocrinol Diabetes Nutr. 2023;70(4):277–85. doi:10.1016/j.endien.2023.02.007

29. Breen L, Phillips SM. Skeletal muscle protein metabolism in the elderly: Interventions to counteract the “anabolic resistance” of ageing. Nutr Metab. 2011;8(1):68. doi:10.1186/1743-7075-8-68

30. Kumar V, Atherton PJ, Selby A, Rankin D, Williams J, Smith K, et al. Muscle Protein Synthetic Responses to Exercise: Effects of Age, Volume, and Intensity. J Gerontol A Biol Sci Med Sci. 2012;67(11):1170–7. doi:10.1093/gerona/gls141