Original Article

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Physiotherapy Section

# Impact of Lower Limb Muscle Strength on Forward Reactive Stepping in Diabetic and Non Diabetic Patients: A Cross-sectional Study

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## ABSTRACT

**Introduction:** Diabetes Mellitus (DM) is a chronic metabolic disorder characterised by persistent hyperglycaemia, which leads to systemic complications affecting the musculoskeletal and nervous systems. This contributes to lower limb weakness, sensory deficits, and impaired postural control, thereby increasing the risk of falls. While most balance assessments focus on anticipatory control. Reactive balance is critical for responding to sudden disturbances, which is often overlooked. The Balance Evaluation System Test (BESTest) includes a reactive balance component, making it a suitable tool for this purpose.

**Aim:** To evaluate the impact of lower limb muscle strength on forward reactive stepping in diabetic and non diabetic patients.

**Materials and Methods:** A cross-sectional study was conducted among 46 diabetic (aged 45-60 years, diabetes duration 3-5 years) and 46 non diabetic individuals in the Department of Endocrinology and Physiotherapy Outpatient Department (OPD) Sri Ramachandra Institute of Higher Education and Research (SRIHER), Chennai, Tamil Nadu, India, from February 2025 to April 2025. Diabetic neuropathy patients were excluded using the Diabetic Neuropathy Symptom Score. Handheld Dynamometer (HHD) was used to measure the strength of hips abductors, knee extensors and ankle plantar flexors. Forward reactive stepping was assessed through the compensation stepping correction component of the BESTest, and parameters like First Step Length (FSL) and First Step Time (FST) were analysed using Tracker 6.1.3 software. Pearson's correlation and Independent t-tests were applied. Effect sizes were reported. Statistical significance was set at p-value<0.05.

**Results:** In diabetic participants, muscle strength showed no significant correlation with FSL but demonstrated moderate negative correlations with FST (r-value=-0.448 to -0.548, p-value <0.001). In non diabetic participants, weak positive correlations were found between muscle strength and FSL (r-value=0.285–0.350), and moderate negative correlations were found with FST (r-value=-0.331 to -0.560). Between-group comparisons showed significant differences in correlations, suggesting diabetes influences the strength- balance relationship.

**Conclusion:** In diabetic individuals, lower limb muscle strength alone may not significantly influence reactive balance, likely due to sensory or neuromotor impairments. Thus, effective balance interventions should include components beyond strength training.


**Keywords:** Diabetes mellitus, Forward stepping, Muscle strength, Postural control, Reactive balance

## INTRODUCTION

The DM is a metabolic disorder that affects the body's ability to regulate blood glucose levels [1]. The DM affects 425 million people globally, projected to reach 629 million by 2045 [2]. Individuals with diabetes have more severe balance disturbances than individuals without diabetes [3]. Diabetes compromises multiple organ systems, such as the musculoskeletal and nervous systems, leading to complications that compromise functional mobility and physical capacity, as shown in individuals with both Type 1 and Type 2 diabetes (T1DM and T2DM) [4,5]. The most common complications of DM are the risk of falls caused by disturbances of balance. Muscle weakness due to muscular system impairment contributes to balance loss and falls in diabetic patients [6]. Muscle weakness, especially in lower limbs, has traditionally been considered a major contributor to balance impairments and reduced reactive stepping ability, both of which are essential for fall prevention [7]. Pathophysiology involves not only muscle weakness but also sensory neuropathy, proprioceptive deficits, and impaired central processing.

Balance, as defined by World Health Organisation (WHO), refers to the capacity to hold or regain one's center of mass within one's limits of stability [8]. It is driven by various sensory inputs, such as vestibular, visual, and somatosensory feedback, which combine to generate postural responses [4]. In diabetic patients, these sensory systems often functions sub optimally due to neuropathic changes, which in turn affect both anticipatory and reactive balance control. While anticipatory balance control involves voluntary movements to maintain stability, reactive balance control refers to the ability to recover from sudden perturbations using rapid compensatory steps. Reactive stepping is an important strategy against falls.

Previous studies states that the majority of the test utilised in diabetes for the measurement of balance, don't measure all aspects of balance [1,9]. Common tools such as Dynamic balance test, Timed Up and Go Test, tandem and unipedal stance, Clinical Test of Sensory Interaction and Balance, Berg Balance Scale, Tinetti Performance-Oriented Mobility Assessment, Functional Reach Test, the Dynamic Gait Index, and Activity-Specific Balance Confidence Scale focus on anticipatory postural control without focusing on reactive balance. Out of the various balance assessment tools, the Balance Evaluation Systems Test (BESTest) is among the few that specifically quantifies reactive stepping responses through lean-release method. This test gives an overall assessment of balance and therefore, is a worthwhile tool for screening for balance deficits in diabetic individuals [9].

A variety of factors may influence balance in diabetes, including muscle weakness, plantar insensitivity, proprioception, age, cognition, vision [9]. Prior studies reports that decreased reactive balance in diabetic individuals may be linked to plantar insensitivity and muscle weakness [7]. Diabetes causes atrophy and muscle weakness, especially in the lower limbs. Research has determined that lower-limb muscle weakness, especially hip abductors, knee extensors, and ankle plantar flexors, is related to reduced reactive stepping [10].

Muscle strength in diabetic patients is commonly assessed using Manual Muscle Testing (MMT) and Handheld Dynamometry (HHD), whereas MMT is a qualitative measurement of muscle function, HHD provides a better objective and reproducible measure of the output force of the muscle [11].

The study was conducted to examine the impact of lower limb muscle strength on forward reactive stepping in diabetic patients. Few studies have examined this specifically in non neuropathic diabetic adults - Explicitly stated as the research gap. Given the growing prevalence of diabetes and its complications, this research is both timely and clinically relevant. Identifying the connection between muscle strength and reactive balance is crucial for designing interventions that effectively reduce fall risk and enhance daily functioning, and contribute to the good health and well-being of people with diabetes.

## MATERIALS AND METHODS

A cross-sectional study was conducted among 46 diabetic (aged 45-60 years, diabetes duration 3-5 years) and 46 non diabetic individuals in the Department of Endocrinology and Physiotherapy OPD, Sri Ramachandra Institute of Higher Education and Research (SRIHER), Chennai, Tamil Nadu, India. Study duration was three months (Feb-April), and data collection was conducted in February 2025 and analysed in mid of April 2025. The Institutional Ethics Committee for Student's projects approved the study (Ref: C SP-III/25/JAN/15/25). The trial was also registered in the Clinical Trial Registry - India (CTRI/2025/03/082188).

**Inclusion criteria:**

- **Diabetic group:** Participants of both genders aged 45-60 years with a confirmed diagnosis of T1DM or T2DM of 3-5 years' duration were included. This duration was selected to enroll participants with established diabetes but without long-term complications, such as neuropathy. Participants were required to ambulate independently without assistive devices and have no history of major foot complications (e.g., amputations or severe ulcers).
- **Control group:** The healthy control group included participants of both genders aged 45-60 years with no history of diabetes or other chronic metabolic, neurological or orthopaedic conditions. Controls were matched to the diabetic group for age and gender. A Body Mass Index (BMI) range of 18.5-30 kg/m² was applied for both groups to minimise confounding effects on balance and stepping performance.

**Exclusion criteria:** Participants were excluded if they had neurological disorders (e.g., Parkinson's disease, stroke) affecting balance, musculoskeletal conditions limiting mobility (e.g., severe arthritis or lower limb surgery within the past 6 months), or a score ≥1 on the Diabetic Neuropathy Symptom Score.

**Sample size calculation:** A total of 92 participants (46 per group) was determined a priori using G*Power 3.1 software, assuming a medium effect size (Cohen's d=0.5), α=0.05, and power (1-α) = 0.80. This calculation was based on previous studies examining muscle strength and balance in individuals with diabetes.

### Study Procedure

The study was explained to individuals meeting the inclusion criteria, and informed consent was obtained. Lower extremity muscle strength was assessed using an HHD in a standardised position, testing the hip abductors, knee extensors, and ankle plantar flexors on both sides. Each muscle group was tested isometrically in a supine position, with a bolster placed under the knee to support a slight flexion angle for the knee extensors. During each trial, participants gradually increased muscle force to a maximum voluntary contraction for two seconds, holding it for five seconds. For each muscle group, three trials were taken with a one to two-minutes rest period between trials to prevent fatigue. The peak force value, measured in grams, was recorded for analysis. The HHD has previously demonstrated high intra-rater and inter-rater reliability in lower limb testing [Table/Fig-1-4][11,12].

**[Table/Fig-1]:** Testing of reactive forward stepping using BESTest.

**[Table/Fig-2]:** Hip abductors strength testing.

**[Table/Fig-3]:** Knee extensor strength testing.

Forward reactive stepping was assessed using the compensatory stepping correction test from the BESTest. The BESTest has been previously validated as a reliable tool for assessing compensatory

**[Table/Fig-4]:** Ankle plantar flexors strength testing.

stepping responses [4,7]. Participants were barefoot with a shoulder-width stance, and the examiner provided initial support at the shoulders. Participants leaned forward until their center of mass exceeded the base of support, after which the examiner released the support, prompting the participant to take a step to regain balance. The stepping response was video recorded for analysis. The video analysis frame setting was standardised for uniformity. The tripod center base was aligned with the 76 cm tape center point. The subject's distance from the tripod center was kept at 240cm, and the tripod height was adjusted to 38 cm. The starting position for forward stepping was standardised, with the participant's lateral malleolus at 0 cm on the inch tape. The major stepping parameters assessed were FSL and FST. Three trials were performed, and the minimum values for FSL and FST were selected for analysis. Two observers were positioned on either side of the participant for safety.

Muscle strength from the contralateral limb (supporting leg) was analysed in relation to the stepping response. For participants who stepped with their right leg, left-side muscle strength values were used, and vice versa. In cases where both legs were used for stepping in different trials, separate entries were created to match each side's muscle strength data with the corresponding balance parameters.

**Outcome Measures:**

- Handheld dynamometer (compression load cell-based dynamometer. The device was calibrated to zero before each trial to ensure measurement accuracy.
- Compensatory stepping correction - forward, component from BESTest scale.

## STATISTICAL ANALYSIS

Statistical analysis was performed using JASP (Jeffreys's Amazing Statistics Program), Version 0.19.3. Pearson's correlation analysis was performed to evaluate the correlation between lower limb muscle strength and reactive balance parameters, specifically FSL and FST, within the diabetic and non diabetic groups. Demographic data were derived from descriptive statistics.

## RESULTS

No significant difference between the diabetic and non diabetic groups in terms of age, gender distribution, and BMI was found in [Table/Fig-5]. Normal reference ranges were considered as follows: Fasting Blood Sugar (FBS): 70-99 mg/dL, Post-prandial Blood Sugar (PPBS): 110-140 mg/dL and Hepatitis B antigen (HbA1c): 4.0-5.6%. Participants were confirmed to be non diabetic based on these standard clinical criteria. Clinical parameters, such as duration of diabetes, were only available for the diabetic group.

| Variables | Diabetic (n = 46) (Mean±SD) | Non Diabetic (n=46) (Mean±SD) |
|---|---|---|
| Age (years) | 51.37±5.33 | 51.04±4.60 |
| Gender | 13M/33F | 20M / 26F |
| Duration of diabetes (years) | 4.41±0.81 | NA |
| BMI (kg/m²) | 27.62±3.04 | 26.62±1.75 |
| PPBS (mg/dL) | 228.15±72.30 | 123±5.32 |
| FBS (mg/dL) | 162.59±49.91 | 92.47±3.28 |
| HbA1c (%) | 8.27±1.86 | 5.20±0.13 |

**[Table/Fig-5]:** Demographic data.
BMI=Body mass index; PPBS=Postprandial blood sugar; FBS=Fasting blood sugar; HbA1c=Glycated Haemoglobin; M=Male; F=Female; NA=Not applicable.

The descriptive statistics of lower limb muscle strength and forward reactive stepping parameters, including FSL and FST, for both diabetic and non diabetic groups have been presented in [Table/Fig-6].

| Variables | Diabetic (n=46) Mean±SD | Non Diabetic (n=46) Mean±SD |
|---|---|---|
| Hip abductors R | 10.82±2.77 | 14.61±3.16 |
| Knee extensors R | 11.34±2.71 | 14.34±2.48 |
| Ankle PF R | 11.30±2.54 | 16.34±2.96 |
| Hip abductors L | 9.79±2.10 | 14.05±2.65 |
| Knee extensors L | 11.24±2.87 | 13.87±2.17 |
| Ankle PF L | 10.88±2.37 | 15.76±2.56 |
| First step length (FSL, cm) | 44.05±9.93 | 48.90±9.86 |
| First step time (FST, ms) | 424.22±130.63 | 393.54±65.36 |

**[Table/Fig-6]:** Descriptive statistics of muscle strength and stepping parameters.

In the diabetic group, the correlation between lower limb muscle strength and FSL was not statistically significant, although all three muscle groups showed very weak correlations [Table/Fig-7]. Conversely, a moderate negative correlation was found between step time and the strength of all three muscle groups. This indicates that greater muscle strength is associated with shorter step initiation times, reflecting faster compensatory responses during forward balance recovery.

| Muscle group | FSL | | FST | |
|---|---|---|---|---|
| | r-value | p-value | r-value | p-value |
| Hip abductors | 0.156 | 0.260 | -0.448 | p<0.001 |
| Knee extensors | -0.026 | 0.852 | -0.515 | p<0.001 |
| Ankle plantar flexors | 0.108 | 0.438 | -0.548 | p<0.001 |

**[Table/Fig-7]:** Correlation of muscle strength with FSL and FST in the diabetic group.
n=46. A p-value<0.05 was statistically significant. FSL: First step length; FST: First step time

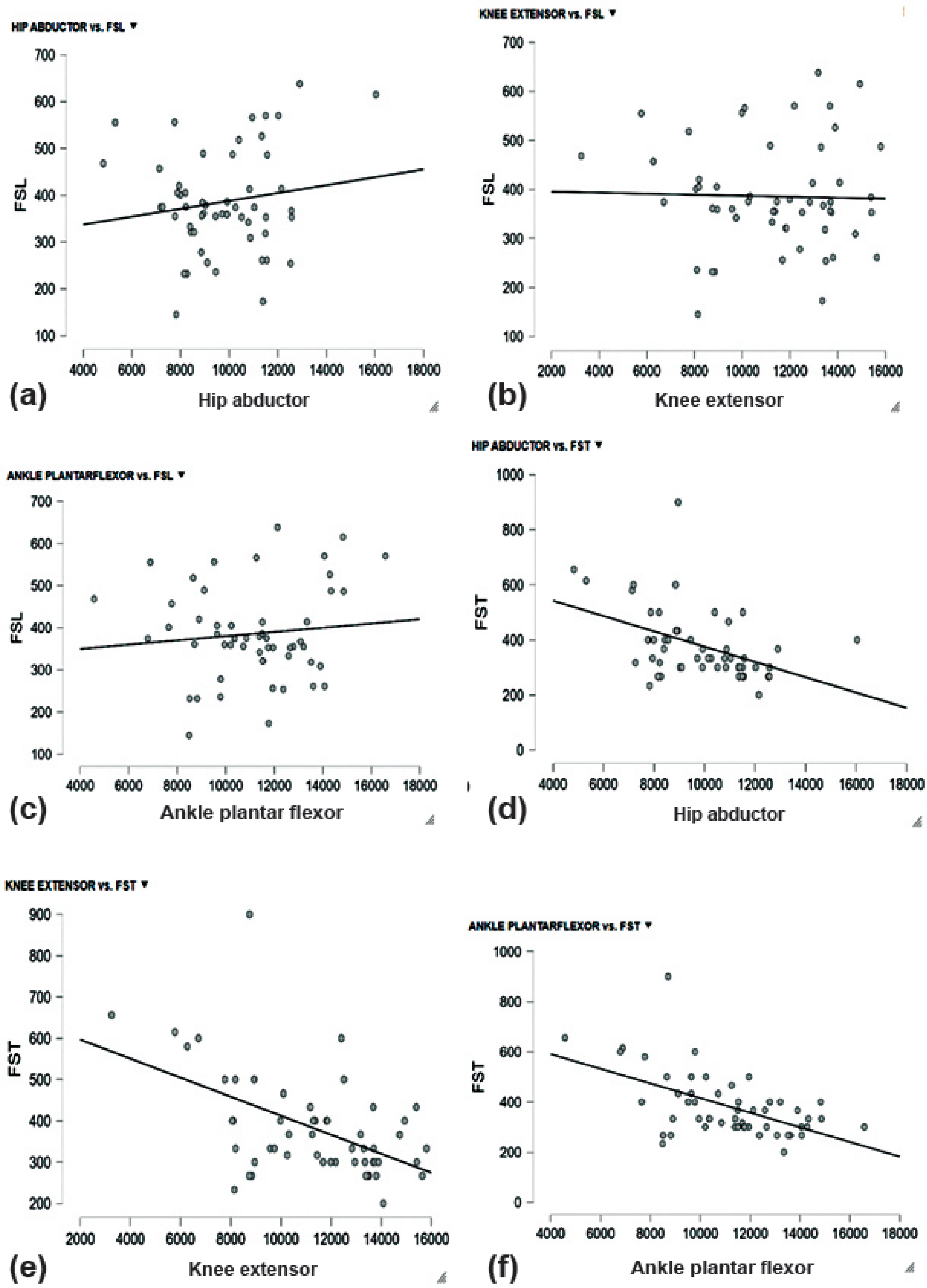
Scatter plots illustrating the relationship between the isometric strength of three lower limb muscle groups and two reactive stepping parameters for 46 diabetic participants. Each point represents a single participant. The X-axis represents muscle strength (in kg) for the respective muscle group, and the Y-axis represents either FSL (in cm) or FST (in ms). A linear regression line is included in each plot to visualise the trend [Table/Fig 8a-f].

In the non diabetic group, weak but statistically significant positive correlations were found between FSL and the strength of knee extensors and ankle plantar flexors [Table/Fig-9]. Additionally, muscle groups (hip abductors, knee extensors) demonstrated moderate negative correlations with step time.

Six scatter plots (a-f) illustrating the relationship between the isometric strength of three lower limb muscle groups and two reactive stepping parameters for 46 non diabetic participants. Each point represents a single participant. The x-axis represents muscle strength (in kg) for the respective muscle group, and the y-axis represents either FSL (in cm) or FST (in ms). A linear regression line is included in each plot to visualise the trend [Table/Fig-10a-f].

## DISCUSSION

The present study aimed to examine the impact of lower limb muscle strength on forward reactive stepping in diabetic patients, with a particular focus on understanding whether diabetes influences the correlation between muscle strength and reactive balance parameters. The results indicate that hip abductor, knee extensor, and ankle plantar flexor strength have a significant effect on reactive stepping responses, which are essential for reducing fall risk in this



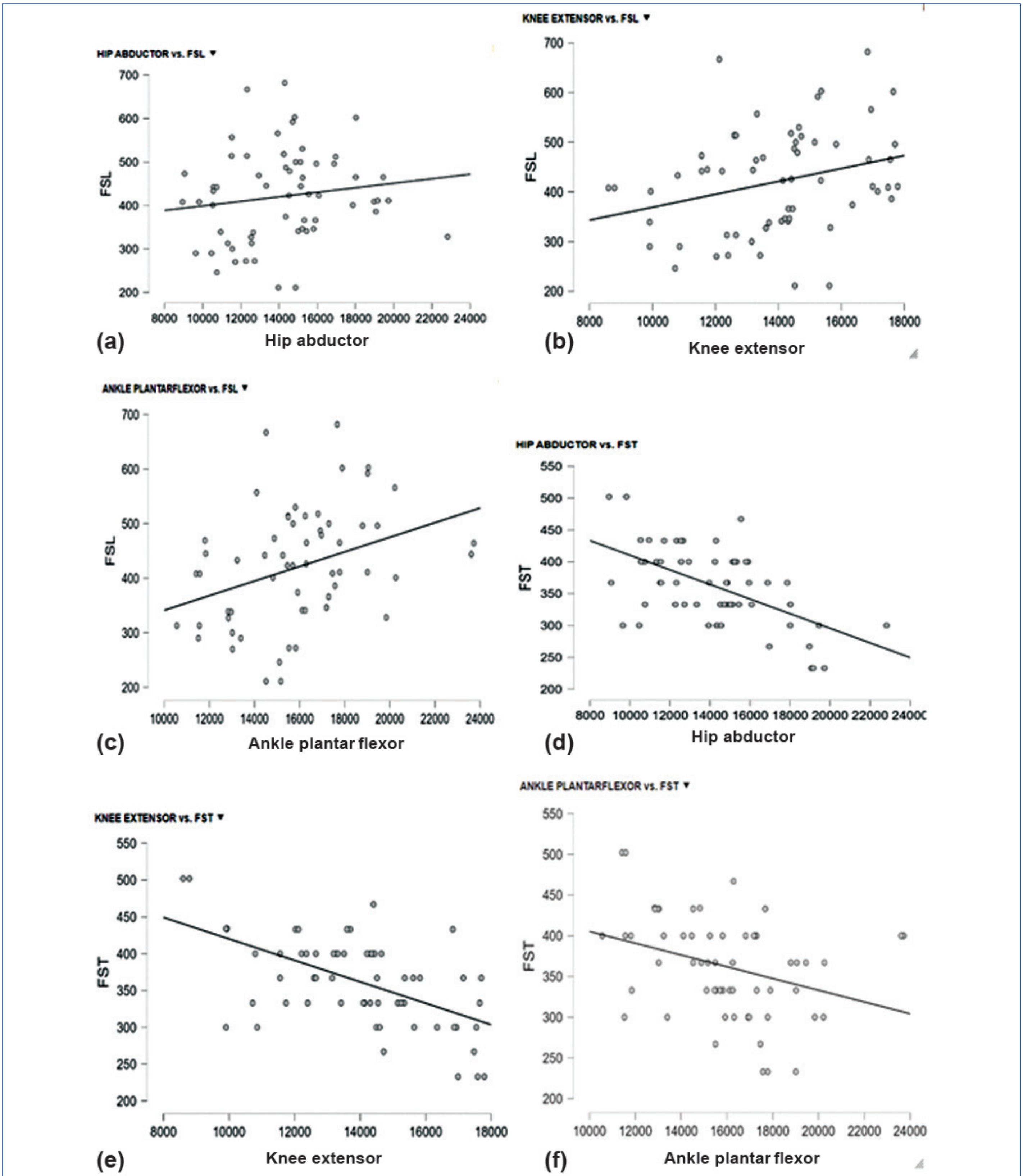

**[Table/Fig-8]:** Scatter plot correlation (diabetic group). Correlation with First Step Length (FSL) (a-c): The plots show the relationship between FSL and the strength of: (a) Hip abductors (r=0.156); (b) Knee extensors (r=-0.026); and (c) Ankle plantar flexors (r=0.108). None of these correlations were statistically significant (p>0.05), indicating that muscle strength did not significantly influence step length. Correlation with First Step Time (FST) (d-f): The plots show the relationship between FST and the strength of: (d) Hip abductors (r=-0.448); (e) Knee extensors (r=-0.515); and (f) Ankle plantar flexors (r=-0.548). All three correlations were statistically significant (p-value<0.001) and moderate, indicating that greater muscle strength was associated with faster step initiation times.

| Muscle group | FSL | | FST | |
|---|---|---|---|---|
| | r value | p-value | r value | p-value |
| Hip abductors | 0.145 | 0.266 | -0.560 | p<0.001 |
| Knee extensors | 0.285 | 0.026 | -0.559 | p<0.001 |
| Ankle plantar flexors | 0.350 | 0.006 | -0.331 | p=0.009 |

**[Table/Fig-9]:** Correlation of muscle strength with FSL and FST in non diabetic group. n=46. A p-value<.05 was statistically significant. FSL: First step length; FST: First step time.

population. However, the findings also demonstrate that diabetes may alter the typical strength-balance relationship, as observed in the diabetic group. Previous studies have highlighted the contribution of the stance (contralateral) leg in maintaining postural stability during balance recovery, which justifies focus on contralateral limb strength in relation to reactive stepping [13,14].

From a neurophysiological perspective, these relationships can be explained by the role of muscle strength in generating rapid joint




**[Table/Fig-10]:** Scatter Plot Correlation (Non diabetic Group). (a-c): Scatter Plot Correlation (Non diabetic Group). Correlation with First Step Length (FSL): The plots show the relationship between FSL and the strength of (a) Hip abductors (r=0.145), (b) Knee extensors (r=0.285), and (c) Ankle plantar flexors (r=0.350). The correlations for knee extensors (p=0.026) and Ankle plantar flexors (p=0.006) were statistically significant, indicating that greater strength in these muscle groups was associated with longer recovery steps. The correlation for hip abductors was not significant (p>0.05). (d-f): Correlation with First Step Time (FST): The plots show the relationship between FST and the strength of (d) Hip abductors (r=-0.560), (e) knee extensors (r=-0.559), and (f) ankle plantar flexors (r=-0.331). All three correlations were statistically significant (p<0.01) and moderate, indicating that greater muscle strength was associated with faster step initiation times.

torques and supporting efficient motor unit recruitment. In non diabetic participants, this neuromuscular advantage translates into both faster steps and longer recovery steps. However, in diabetic individuals, the correlations between muscle strength and step length were weak and non significant. This may be due to sensory and neuromotor impairments common in diabetes, such as peripheral neuropathy, impaired proprioception, slowed neural conduction, and reduced muscle quality. These deficits likely reduce the ability to translate muscle force into effective step placement, limiting step length despite preserved strength.

The current study findings revealed a significant moderate negative correlation between hip abductor strength and FST, which supports previous research highlighting the critical role of hip abductor strength in maintaining mediolateral stability during balance recovery [10]. Importantly, this role extends beyond forward perturbations: in real-world fall scenarios, particularly during lateral or sideways balance losses, rapid activation of the hip abductors is crucial to control lateral sway and prevent falls. Since sideways falls are strongly associated with hip fractures in older and diabetic populations, the clinical relevance of strengthening the hip abductors is especially high. Additionally, a similar negative correlation was found between knee extensor strength and the duration of first step initiation. This suggests that individuals with greater knee extensor strength can initiate compensatory steps more quickly, consistent with earlier evidence that linked knee extensor explosive strength to shorter swing time during reactive stepping in healthy adults [15]. However, in diabetic patients, the correlation between knee extensor strength and first step initiation was weaker compared to non diabetic, suggesting that diabetes might impact the efficiency of the neuromuscular response, potentially delaying balance recovery.

Ankle plantar flexors exhibited the moderate negative correlation with FST in the diabetic group (r=-0.548), followed by knee extensors (r=-0.515), and hip abductors (r=-0.448). This supports the role of the gastrocnemius and soleus muscles in generating the necessary forward and vertical forces to reduce step time [10]. It is important to note, however, that reactive stepping is a time-critical task, and explosive strength rather than maximal strength may be more relevant in determining the speed of compensatory responses.

Despite this, no significant correlation was found between muscle strength and FSL in diabetic individuals, whereas positive significant correlations were found between knee extensor and ankle plantar flexor strength and step length in non diabetic individuals. This key finding suggests that in diabetic individuals, central processing or sensory integration deficits may override muscular capability, limiting the translation of strength into functional step length. In other words, the influence of muscle strength on step length may be masked by impairments in sensory feedback and neuromotor integration, both of which are frequently compromised in diabetes [4,8].

The present study findings are supported by a previous article, which states that muscle weakness is present even in diabetic patients without neuropathy. This early impairment may weaken the typical correlation between muscle strength and balance, as reduced strength and muscle quality can limit neuromuscular efficiency [16].

The use of the BESTest scale for assessing reactive balance was a key strength, as it specifically targets compensatory stepping. Traditional balance tests such as Timed Up and Go or Berg Balance Scale focus more on anticipatory balance and do not assess reactive balance [1,9]. Like the previous study, the current research used the BESTest to assess balance. Their results support the scale's sensitivity in detecting balance improvements, reinforcing its suitability for evaluating reactive stepping in diabetic patients [17]. Additionally, employing a handheld dynamometer for muscle strength assessment increased the precision of our measurements, ensuring a more accurate correlation between muscle strength and balance parameters. By excluding diabetic neuropathy patients using the Diabetic Neuropathy Symptom Score, authors were able to isolate the effects of muscle strength from potential sensory deficits, which are known to significantly affect balance and mobility outcomes in individuals with peripheral neuropathy [18]. This exclusion is critical, as previous research, muscle weakness in diabetes is often accompanied by nerve damage, which could have confounded our results [12,19].

**Clinical implications:** The present study suggests that lower limb strength training alone is insufficient to improve reactive balance in diabetic individuals. Therefore, effective rehabilitation must integrate resistance training with explosive strength drills and perturbation-based balance exercises. Furthermore, interventions should incorporate sensory integration and dual-task training to address the underlying neuromotor deficits. Clinically, it is recommended to screen diabetic patients using reactive balance assessments like the BESTest to identify those at highest risk and prioritise them for these comprehensive, multi-component interventions.

**Gender considerations:** Although gender differences were not a primary focus of the study, the imbalanced gender distribution between groups is a notable consideration. As gender can influence muscle strength and balance strategies, future research should aim for gender-balanced cohorts to determine if the relationship between strength and reactive balance is moderated by gender, allowing for more tailored rehabilitation programs.

Hence, strengthening the hip abductors, knee extensors, and ankle plantar flexors can enhance stepping responses and reduce fall risk in individuals with diabetes. However, the present study suggests that diabetes may affect the correlation between muscle strength and reactive balance. This finding highlights the need for developing interventions that not only focus on improving lower limb muscle strength but also address the neuromotor impairments that are common in individuals with diabetes. This contributes to the existing body of knowledge on diabetes and balance control.

### Limitation(s)

The present study has several limitations. First, it did not assess other neuromuscular factors such as proprioception, sensory integration, or core stability, all of which are known to influence reactive balance responses. The absence of these evaluations may partly explain why muscle strength alone was not strongly correlated with step length in diabetic participants. Second, individual variations in postural control strategies were not analysed, which could have affected balance recovery outcomes. Potential confounding variables, such as undetected subclinical neuropathy, variability in physical activity levels, and medication use, may also have influenced the results.

## CONCLUSION(S)

The present study suggests that in individuals with diabetes, lower limb muscle strength alone does not strongly influence reactive balance, such as step length. This indicates that diabetes may interfere with how strength contributes to balance, likely due to sensory or neuromotor impairments. As a result, lower limb strength training alone may not be sufficient to improve balance in the diabetic patients. Effective rehabilitation should include not only strengthening exercises but also interventions targeting sensory deficits and postural control to reduce fall risk and enhance stability in diabetic population.

Future research should adopt a more comprehensive approach by including assessments of sensory and neuromotor function alongside muscle strength. Longitudinal studies could further explore how the progression of diabetes affects balance control. In addition, intervention studies that combine strength training with proprioceptive exercises, balance retraining, and postural control strategies may provide deeper insights into improving reactive balance and reducing fall risk in diabetic individuals.

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- Manual Googling: Jan 03, 2026
- iThenticate Software: Jan 05, 2026 (8%)

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