IJBPAS, February, 2025, 14(2): 854-871

ISSN: 2277–4998

International Journal of Biology, Pharmacy and Allied Sciences (IJBPAS)

'A Bridge Between Laboratory and Reader'

www.ijbpas.com

EXPLORING THE IMPACT OF ACCELERATED MUSCLE ACTIVATION THROUGH STEP TRAINING ON REACTIVE POSTURAL CONTROL AND CADENCE IN INDIVIDUALS WITH DIABETIC NEUROPATHY - A RANDOMISED CONTROL TRIAL

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Received 4th Nov. 2023; Revised 5th Dec. 2023; Accepted 27th April 2024; Available online 1st Feb. 2025

https://doi.org/10.31032/IJBPAS/2025/14.2.8700

ABSTRACT

Diabetic neuropathy is a common complication of diabetes that causes nerve demyelination, resulting in reduced sensation, proprioception, and muscle strength, power generation, mobility. This condition also leads to balance abnormalities (reactive and proactive postural control) as well as walking disturbances including slower speed, shorter stride length, and changes in the quality of walking. the objective of the study is to see the impact of fast muscle activation through step training (FAST) on reactive postural control and cadence(steps/min) in subjects with mild diabetic neuropathy. A total of 30 participants with mild diabetic neuropathy were assessed Michigan Polyneuropathy Examination (MNSI)randomly assigned to two groups for a 4-week study: the FAST exercise group (n=16) and the active control group (n=14). For reactive postural control is a subcomponent of BESTest -reactive postural balance section and for walking cadence measure by total steps per minute. Identify a mean improvement of 2 ± 5.875 and 3.142 ± 9.857 in the experimental and control groups respectively. Both groups showed significant improvement in reactive postural control and gait after intervention ($p<0.05$). However, in an experimental group, most of the subjects showed vast improvements. Whereas group B showed mild to moderate improvement in subjects. The result of the study demonstrated accelerated muscle activation through step training on reactive postural control and cadence in individuals with diabetic neuropathy.

Keywords: Stepping Training, Reactive Postural Control, Cadence, Diabetic Neuropathy

INTRODUCTION

In the current scenario, the description and frequency of Diabetic neuropathies are considered to be the highest chronic complications of diabetes. While up to half of diabetic neuropathy cases may show no symptoms, these individuals are at risk of injuries to insensitive areas if not identified, emphasizing the importance of preventive foot care **[1]**.

Diabetic polyneuropathy is a major complication of diabetes, resulting in reduced sensation, slower walking speed, decreased ankle mobility and muscle strength, as well as challenges in maintaining balance control **[2]**. The prevalence of neuropathy ranges from 8% to 51% in T2DM and remains comparable in T1DM **[3]**. The occurrence of signs and symptoms of nerve damage may manifest in over 25% of diabetes mellitus cases after 10 years and in up to 50% after 20 years **[4]**.

Nerve biopsies of diabetic patients show damage to the myelin sheath and detachment of Schwann cells from axons, **[5, 6]** leading to difficulties in signal transmission **[7]**. The altered function of the blood-nerve barrier increases permeability, allowing substances like albumin and immunoglobulin G to penetrate the endoneurium, resulting in thickening of outer layers and edema formation **[8]**. Increased occurrence of Advanced Glycation End Products indicates potential harm to nerve cells **[8, 9]**. Also, there is Oxidative stress, mainly triggered by elevated glucose levels **[10]**. Decreased presence of subsarcolemmal mitochondria, which are important for Na+/K+ATPase function. High blood sugar levels lead to impaired Na+/K+ATPase activity and decreased nerve excitability **[11]**.

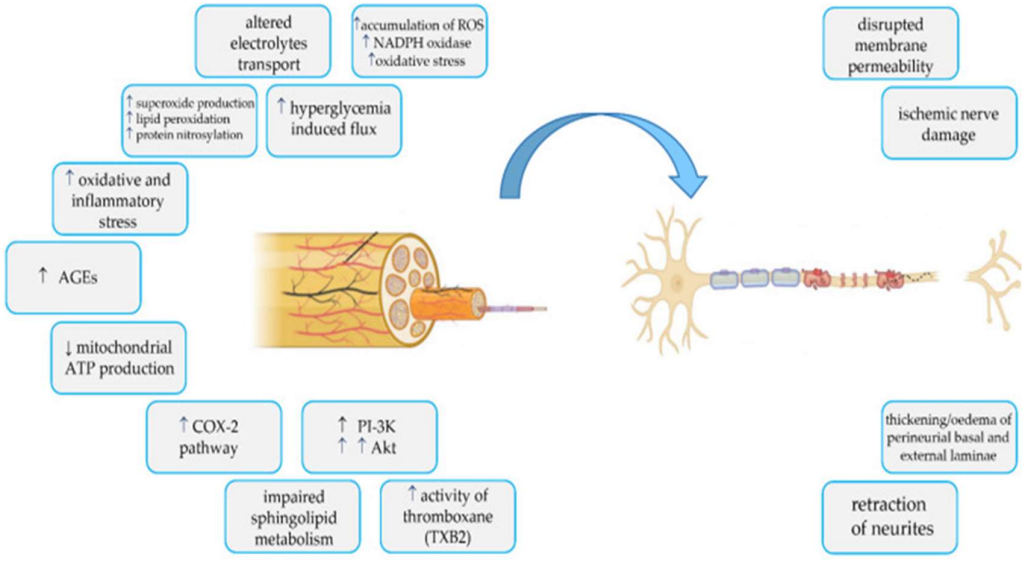

Figure 1: Pathophysiology of DPN [12]

At the onset of the illness, muscle strength is impaired and deteriorates as the disease progresses **[13-15]**. Numerous muscle groups in the body are impacted, particularly influencing the knee's flexor and extensor muscles, as well as the segments of ankle dorsal and plantar flexors in the lower limb **[16]**. Motor nerve damage resulting from diabetic peripheral neuropathy leads to increased impairment in the intrinsic muscles of the foot, as well as the ankle and knee muscles. **[17]**. Research indicates that non-neuropathic diabetic patients show a decrease in ankle and knee muscle strength ranging from 8% to 15% compared to healthy individuals of the same age. In diabetic patients with DPN, deficits ranging from 25% to 45% have been documented. **[18-21]**.

A complication leads to a decrease in muscle strength, which is connected to the wasting of the lower limbs' distal segments. This atrophy occurs when motor axons are deprived of theirnormal functioning, leading to insufficient re-innervation **[22]**. Several studies have indicated that diabetes accelerate the loss of muscle mass, starting in the muscles of the foot and steadily advancing to the lower legs **[22, 23]**. The decrease in Type 2 fast-twitch muscle fiber activity at a distance is expected, and when combined with the effects of aging and fear of fall, it contributes to decreased mobility and balance. This reduction in physical capability results in difficulty generating quick force around the ankle, even for individuals with mild DPN **[24]**, which can worsen with the progression of sever DPN **[22, 25]**.

In patients with diabetic neuropathy, there is a strong link between reduced muscle strength and impaired mobility which ultimately affect the balance and increase risk of fall **[17, 26]**. Muscle weakness, especially in the legs, plays a significant role in affecting mobility decline. This restricted mobility encompasses various daily activities and significantly affects an individual's independence, particularly when routine tasks like getting up from a chair, climbing stairs, and grocery shopping are hindered **[11]**.

The ability to recover from balance disturbances is crucial in preventing falls. Postural control depends on the interaction between sensory inputs and motor responses via central integrative processing systems and balance response generating joint torques that rotate the body forward, including hip flexion, knee extension, and ankle dorsiflexion, is crucial to activates trunk and leg muscles to counter body sway following support surface perturbation with a short latency period **[27]**. Reactive balance control like stepping strategy, pivoting around the ankle or hip joints, and reaching for support consists of two parts: proactive (pre-slip) and reactive (post-slip). Reactive

and proactive postural control activates trunk and leg muscles to counter body sway following support surface perturbation with a short latency period, and this strategy are crucial in preventing falls after a sudden change in posture **[28, 29]**. However, in diabetes patients with neuropathy, this balance response is delayed, leading to a more extensive displacement of the Centre of Pressure (COP) **[27]**.

Diabetic older adults (DM-OA) exhibit a decline in the ability to generate these torques compared to young adults (YA), leading to significantly greater anterior-posterior (AP) displacement due to the importance of muscle strength in determining AP motion **[27]**. Individuals with diabetic peripheral neuropathy demonstrate slower walking pace, shorter stride length, and lower cadence compared to healthy controls. This is evident in both self-paced and maximal speed conditions, attributed to prolonged double limb support and a widened base for stability during walking **[16]**. Peripheral neuropathy and inactivity may contribute to functional loss in foot and ankle musculature, although detailed descriptions of these motor deficits are scarce. If those with peripheral neuropathy struggle to generate sufficient moments around the ankle during walking, it is anticipated that they will take shorter steps and exhibit a slower walking pace compared to individuals without peripheral neuropathy **[30]**. So the purpose of this study is to identify the benefit of fast fictional activity with stepping training on reactive postural control and cadence (walking speed) in DN subject.

Postural responses about task speed have not received thorough investigation. Stroke survivors displayed improved activation of weakened muscles and better postural reactions while performing a balance task following rapid functional squats and stepping training **[31]**. The FAST protocol aims to enhance proactive and reactive responses, thereby improving reaction time during corrective stepping when regaining balance after tripping in exercises **[31]**. It involves gradual implementation of quick functional movements that engage rapid muscle activation and anticipatory postural control in the leg and trunk muscles, crucial for both stationary and moving balancing tasks. Our approach included various practice conditions guided by a therapist, including blocked practice (repeatedly practicing the same skill under identical conditions) and random practice (introducing variability) **[32]**, all under the guidance of a therapist. The exercise comprises various components:

i. Squat: promoting equal weight distribution **[32]**.
ii. Stepping: key component of protocol leading to rapid muscle activation in the stepping leg to

facilitate swift postural adjustments for maintaining balance **[31]**.

iii. Compensatory activities: Adding intricacy to the stepping routines, these activities present a variety of challenges for participants **[31]**.

Objectives

1. To determine the effect of fast muscle activation with stepping training on reactive postural control in a patient with diabetic neuropathy.
2. To determine the effect of fast muscle activation with stepping training on cadence in a patient with diabetic neuropathy.

MATERIALS AND METHODS

This study utilized a single-blinded randomized controlled design. Ethical approval was gained from the Parul University Institutional Ethics Committee for Human Research (PU – IECHR). A study was conducted in the neurological rehabilitation department of Parul Sevashram Hospital, Parul University. Sample size is calculated by G power and total sample size is 40. Diabetic neuropathy assessed by Michigan neuropathy screening instrument [The MNSI demonstrates superior sensitivity and specificity compared to individual DN tests **[33]**. a lower extremity examination performed, if a clinical examination score of 2.5 or above shows a positive diagnosis of DN. The current research involves individuals who met the predefined criteria, received adequate information and explanation about the study, and provided consent to participate.

Subjects of both genders, aged 45-65 years, with a pre-existing diagnosis of type 2 diabetes mellitus for a minimum of seven years, BMI ranging from 18.5 to 29.9 kg/m2, and the capability to walk without assistance and stand on one leg for more than ten seconds were considered as inclusive criteria. The assessment was based on the Michigan neuropathy screening instrument. Patients presenting with a mild neuropathy score between 2.6 and 4.5 were classified according to the fuzzy model system as having varying severity levels in diagnosing diabetic neuropathy (sensitivity: 89%, specificity: 98%) **[34]**. Patients with diabetic ulcers in one or both feet, inadequate blood sugar control, inner ear infections, non-neuropathic nervous system impairments affecting balance, musculoskeletal issues including spinal and limb deformities, multiple ankle sprains within the past year, severe pain impacting balance, visual impairments unrelated to diabetic neuropathy, and any other factors that disrupt balance apart from B12 deficiency should be excluded as criteria.

Procedure

The patient agreed to take part, then assessments were conducted before randomization. The MNSI and outcome

measures were also evaluated before being assigned randomly to two treatment groups: the FAST group and the active control group. Random allocation was implemented using the paper chit method. The training lasted for a period of 4 weeks with four working sessions per week **[Table 1, 2, 3] [Figure 3, 4, 5]**. After these 4 weeks, outcome measurements were reassessed. A total of 30 subjects were analysed, and the pre-data and post-data on reactive postural control and walking cadence were compared.

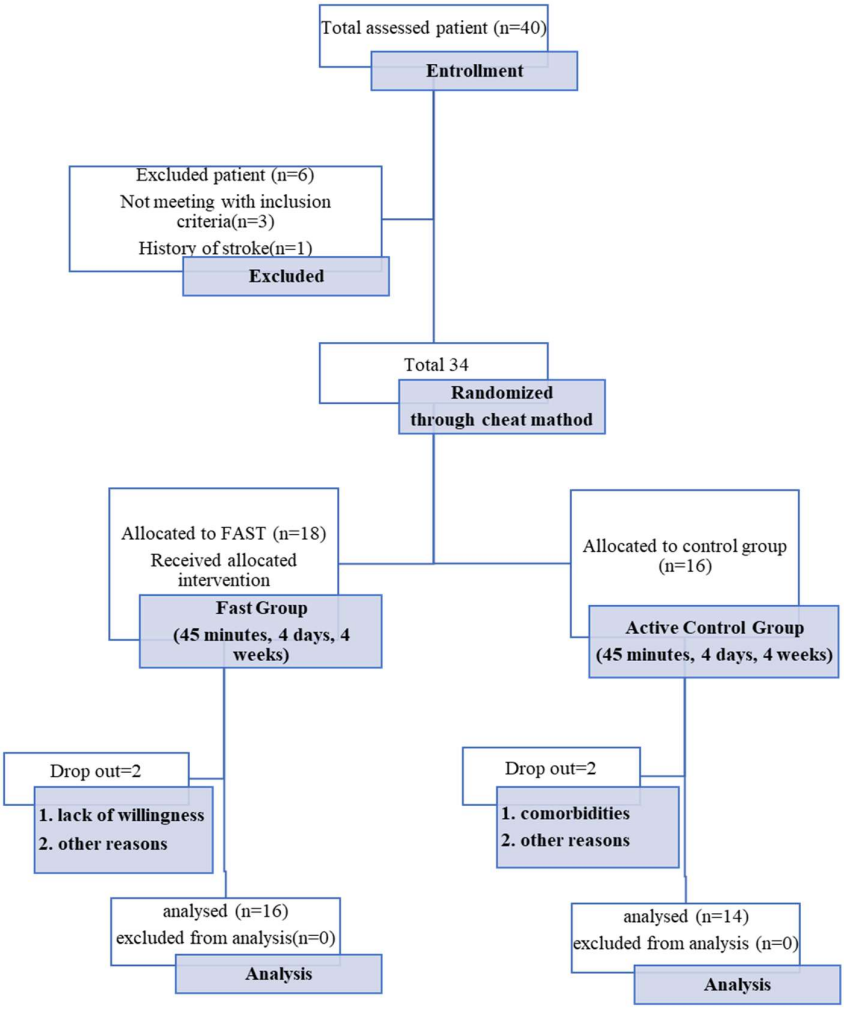

Figure 2: Flow diagram of the progress during the trail phases

Exercise Protocol

Fast Muscle Activation with Stepping Training (Experimental group)

Table 1: Exercise Protocol for Squats

Exercise	Type	Repetition
Squats	30 degrees of hip and knee flexion as fast as possible	5 sets of repetitions
		5 sec of rest between each repetition
		30 sec between each set

Figure 3: Squat Exercise for experimental group

Table 2: Exercise Protocol for Stepping training

Exercise	Type	Repetition
Steps	Simple blocked practice: Stepping leading with each leg	2 sets of 60 repetitions 10 rep/set
	Semi-random practice: Stepping leading with each leg in each direction	5 sets of 5 reps (75 reps with each leg/each side in total)
	Random practice: Stepping leading with a dominant leg in all 3 directions	5 sets of 5 reps (75 reps with each leg/each side in total)
	Random nomination: The therapist randomly nominates the lead leg	20 steps with each leg in all 3 directions
	Concurrent task planning: simple concurrent cognitive task	Repeat all previously mentioned stepping exercises

Figure 4: Forward bending Exercise for experimental group

Table 3: Exercise Protocol for Complementary activities

Exercise	Type	Repetition
Complementary activities	Step over 4 square exercises (similar to four square step test)	Clockwise and anti-clockwise direction
	Additional stepping and bounding activities: Leaning and stepping off a sissel balance fit dome	Stepping onto/off and 60 reps with each leg/side Repeat all previously mentioned stepping exercises

Figure 5: Stepping training on bosu ball for experimental group

Active Control Group

Similar to the FAST program, the active control intervention involves customized activities designed to help the participant restore balance and mobility based on their specific needs and objectives. This physiotherapy intervention includes practicing standing balance and walking activities tailored to tasks, as well as exercises focusing on strengthening and endurance of lower limbs. There is no specialized instruction in rapid stepping responses or structured training for fast over-ground walking (including treadmill training).

Outcome Measurement

The current investigation involved assessing the subject's reactive postural control using the BESTest, which comprises 27 items and a total of 36 tasks. Scores on this scale range from 0 to 3, with higher scores indicating superior performance. Our specific focus was on the fourth component of the BESTest scale for evaluating reactive postural control, which has a maximum score of 18 and includes six subcomponents: in-place responses forward and backward, compensatory stepping corrections forward, backward, lateral left, and lateral right. The BESTest showed high interrater relative reliability (ICC ≥ 0.933), with the subsystems demonstrating excellent consistency between raters (ICC = 0.964-0.992) and moderate to strong consistency over time (test-retest reliability, ICC = 0.667-0.957) **[35]**.

The second measure of outcome involves using a stopwatch to track the time it takes for the subject to walk from one end of the track to the other at their own pace. The stopwatch is started when the leading foot touches the ground and stops when the trailing foot leaves it. The final result is determined by calculating the mean of 5 trials. Utilizing a stopwatch for cadence measurement is highly reliable, valid, and sensitive with high specificity **[36]**.

Statistical Analysis

The statistical analysis in this study made use of IBM SPSS version 27.0.1 software.

To assess the normal distribution of variables, the Shapiro-Wilk test was utilized, confirming that these variables adhere to a normal distribution. Data was analysed using a paired t-test to compare pre- and post-treatment assessments for reactive postural control and cadence within each group, as well as to investigate differences between the two groups.

RESULTS

Experimental Group

Table 4: Descriptive of pre and post data of Experimental Group

Outcome measure (Pre-Post)	Sample Size	Minimum	Maximum	Mean	Std. Deviation
RPC Pre	16	6	13	10.625	2.774
RPC Post	16	10	17	14.375	2.503
Cadence Pre	16	80	110	101.375	10.098
Cadence Post	16	92	120	111.375	8.991

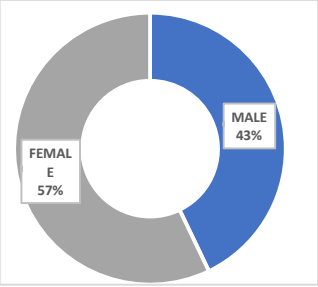

Figure 6 - Ratio of Male and Female in Experimental Group

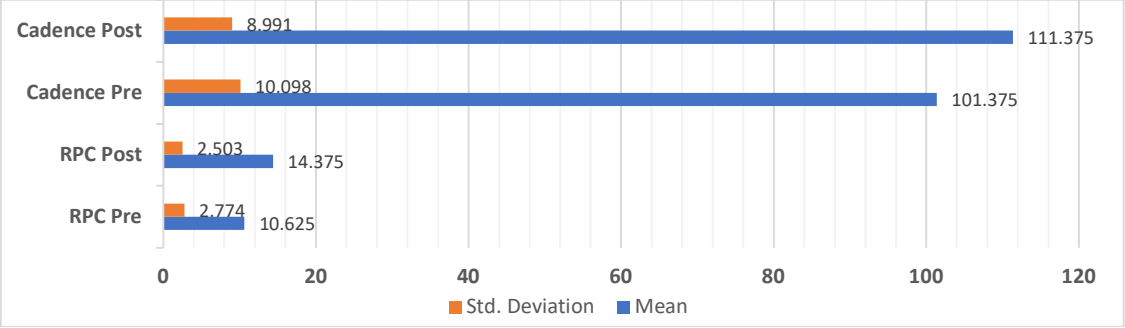

Figure 7: Comparison of mean and SD of RPC and cadence of in experimental group

Conclusion of Experimental Group

Reactive postural control (RPC): In the experimental group, the minimum value for pre-measure was 6 and the maximum value was 13. Which increased a minimum value of 10 and a maximum value of 17. Also, the mean was 10.625 at the time of the pre-measure with SD 2.774, Which was increased in the post-measure to 14.375 with SD 2.503.

Cadence: In the experimental group, the minimum value for pre-measure was 80, and the maximum value was 110. Which increased a minimum value of 92 and a maximum value of 120. Also, the mean was 101.375 at the time of the pre-measure with SD 10.098, Which was increased in the post-measure to 111.375 with SD 8.991.

Table 5: Test of significance of experimental group

Difference	Paired Differences					t	df	p-value(α =0.05)
	Mean of Difference	Std. Deviation of Difference	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
RPC Pre – RPC Post	2	0.894	0.223	1.294	3.157	8.944	15	<0.01
Cadence Pre– Cadence Post	5.875	3.283	0.820	4.125	7.624	7.156	15	<0.01

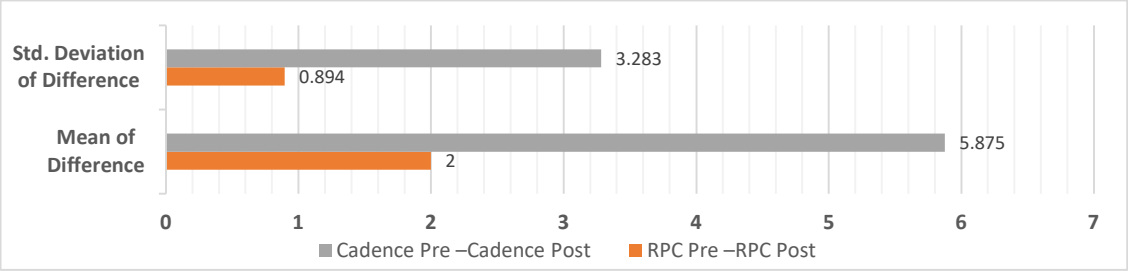

Figure 8-Comparison of mean of difference and SD difference in pre and post data (experimental group)

Conclusion of Tests of Significance (Experimental Group)

RPC: In an experimental group, the mean difference was 2 with an SD of difference 0.894 test statistic t was 8.944 with p-value <0.001 which is less than 0.05. We can conclude post the measure was significantly increased after treatment. i.e., treatment was significantly effective in improving RPC

Cadence: In an experimental group, the mean difference was 5.875 with an SD of difference of 3.283. test statistic t was 7.156 with p value< 0.01 which is less than 0.05. We can conclude post the measure was significantly increased after treatment. i.e., treatment was significantly effective in improving cadence.

Control Group

Table 6: Descriptive of pre and post data of Control Group

Outcome measure (Pre-Post)	Sample Size	Minimum	Maximum	Mean	Std. Deviation
RPC Pre	14	10	16	12.714	2.138
RPC Post	14	13	18	15.428	1.902
Cadence pre	14	84	118	103.142	13.158
Cadence post	14	98	120	109.857	8.839

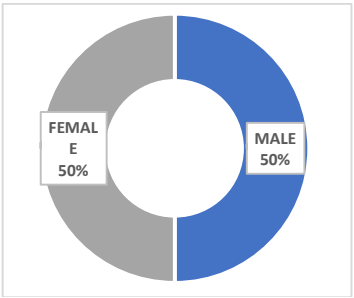

Figure 9: Ratio of Male and Female in Control Group

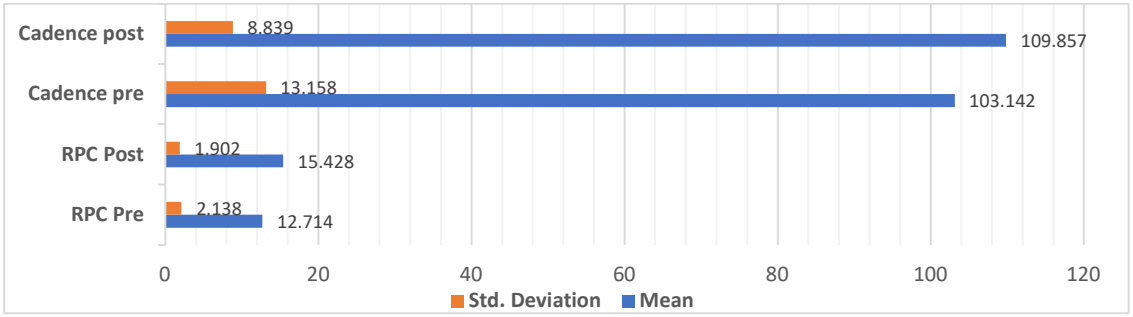

Figure 10: Comparison of mean and SD of RPC and cadence of in control group

Conclusion of Control Group

RPC: In a control group, the minimum value for pre-measure was 10 and the maximum value was 16. Which increased the minimum value to 13 and the maximum value to 18. Also, the mean was 12.714 at the time of pre-measure with SD 2.138, Which was increased in the post-measure to 15.428 with SD 1.902

Cadence: In a control group, the minimum value for pre-measure was 84, and the maximum value was 118. Which increased the minimum value to 98 and the maximum value to 120. Also, the mean was 103.142 at the time of pre-measure with SD 13.158, Which was increased in the post-measure to 109.857 with SD 8.839.

Table 7: Test of significance of control group

Difference	Paired Differences					t	df	p-value (α =0.05)
	Mean of Difference	Std. Deviation of Difference	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
RPC Pre –RPC Post	3.142	1.292	0.345	2.396	3.889	9.099	13	<0.001
Cadence Pre – Cadence Post	9.857	2.381	0.636	2.330	5.446	10.522	6	<0.001

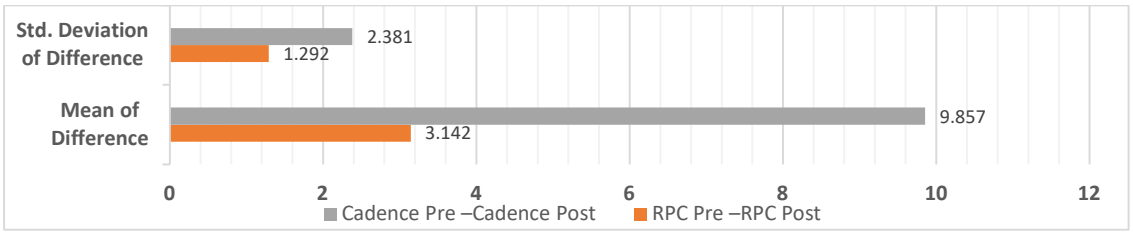

Figure 11: Comparison of mean of difference and SD difference in pre and post data (control group)

Conclusion of Tests of Significance (Control Group)

RPC: In a control group, the mean of difference was 3.142 with an SD of difference of 1.292 test statistic t was 9.099 with a p-value of <0.001 which is less than 0.05. We can conclude post the measure was significantly increased after treatment. i.e., after applying the treatment RPC improved significantly.

Cadence: In a control group, the mean difference was 9.857 with an SD of

difference of 2.381 test statistic t was 10.522 with a p-value <0.001which is less than 0.05. We can conclude post the measure was significantly increased after treatment. i.e., after applying the treatment Cadence improved significantly.

DISCUSSIONS

One prevalent complication arising from diabetes is Diabetic Peripheral Neuropathy (DPN). This condition, affecting almost half of individuals with diabetes, gives rise to a range of issues including impaired peripheral sensation, diminished proprioception, slower walking speed, reduced step length, limited ankle motion, decreased muscle strength, and deficiencies in both static and dynamic balance control **[2]**. The impact of DPN on functional abilities significantly elevates the risk of falls when compared to individuals of the same age without diabetes-related complications **[4]**.

Conducted at Parul Sevashram Hospital, this study aimed to evaluate the impact of fast muscle activation through stepping training on reactive postural control in individuals with diabetic neuropathy. The four-week intervention program was designed to measure various outcome parameters. The analysis of results revealed a significant improvement in both groups, highlighting enhanced reactive postural control and increased cadence. Consequently, the study concludes that the implemented intervention effectively contributed to positive changes in these key aspects.

A pivotal factor in diminishing the occurrence of falls and averting fall-related injuries is the incorporation of balance training exercises **[37]**. Ahmad I and Verma S stated that balance training activates mechanoreceptors in the spindle, Golgi tendon organ, and responsive joint capsule. This increases sensory feedback from the foot, ankle, and trunk **[38]**. Furthermore, Hedayati *et al*. **[39]** note that improving balance through strength exercises is linked to the activation of large and fast-twitch muscles, as well as the stimulation of muscle spindles. This increase helps in better coordination of muscles involved in simultaneous contraction activities. **[39]**.

The FAST protocol involves repeated direction-stepping training, a strategy designed to amplify both proactive and reactive postural control. This, in contrast, results in enhancements in muscle engagement, response time, and the body's reaction to internal disturbances. This study reveals that regular engagement in exercises such as fast-function squats and stepping training contributes significantly to the enhancement of muscle activation and reaction time. This improvement can be credited to the use of light loads at maximum movement speed, a technique recognized for causing both muscular and neural changes. Known as dynamic or explosive training,

this approach involves rapid contractions with short times to reach peak tension, high rates of tension development, and increased discharge frequencies in single motor units **[40]**.

The integration of stepping training and fast-function squats, employing both block practice and random practice, plays a pivotal role in enhancing repeated direction-predictable perturbations. This internal perturbation, which is further intensified by the FAST protocol plays a crucial role in enhancing the effectiveness of postural reactions to disturbances, leading to a quicker restoration of balance.

Perturbations in predictable direction and timing lead to cortical activities before the disturbances begin. These activities indicate the involvement of a central set that modifies the state of the central nervous system, preparing for automatic postural responses to perturbations based on prior experiences **[41, 42]**. All the participants continued throughout the study and at the end of 4 weeks of intervention, group A (fast muscle activation and stepping training) and group B (active control group) both groups showed significant improvement. But in group A most of the subjects showed vast improvements. Whereas group B showed mild to moderate improvement in subjects. Present study accepts alternative hypothesis that there are significant results of fast muscle activation with stepping training on reactive postural control and walking cadence in a patient with diabetic neuropathy

Over four weeks, 30 subjects participated in exercises to assess the impact on reactive postural control (measured by BESTest) and cadence. Pre-test and post-test measurements were used to capture changes over the intervention period. Paired t-tests were employed to analyze the data, along with calculations of mean and standard deviation for both pre- and post-measures. The results showed significant improvement in patients who took part in fast functional movements and stepping training within the active group. The interventions were carefully standardized, considering factors such as frequency, duration, and weekly volume of training. Additionally, specific exercise patterns were meticulously detailed to provide a comprehensive understanding of the structured interventions applied.

CONCLUSION

Based on the research results, both interventions administered to the experimental and control groups had a positive impact on reactive postural control and cadence in the experimental group. Many participants in this group demonstrated significant enhancements. In contrast, the control group exhibited slight to moderate improvements among its members.

ACKNOWLEDGMENTS

The author conveyed their appreciation to the participant for volunteering to take part in the research.

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