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EFFECT OF PROGRESSIVE RESISTANCE TRAINING COMBINED WITH NEUROMUSCULAR ELECTRICAL STIMULATION ON BALANCE AND FUNCTIONAL MOBILITY IN INDIVIDUALS WITH MULTIPLE SCLEROSIS: A SECONDARY ANALYSIS OF A RANDOMIZED CONTROLLED TRIAL.

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Abstract

Background

Multiple sclerosis (MS) is a chronic immune-mediated neurological disorder characterized by inflammation, demyelination, and progressive neurodegeneration within the central nervous system. Balance impairment, muscle weakness, gait dysfunction, and reduced functional mobility are among the most disabling manifestations of MS, contributing substantially to falls, loss of independence, and diminished quality of life. Exercise-based rehabilitation has emerged as a cornerstone of physiotherapy management, with progressive resistance training and neuromuscular electrical stimulation (NMES) demonstrating promising effects on neuromuscular performance. However, evidence describing the isolated effects of resistance training combined with NMES on balance outcomes in ambulatory individuals with MS remains limited.

Objective

To evaluate the effectiveness of progressive resistance training combined with neuromuscular electrical stimulation in improving balance and functional mobility among ambulatory individuals with multiple sclerosis.

Methods

This secondary analysis utilized data from participants allocated to the resistance training with NMES arm of a randomized controlled trial conducted in the study instituton. Ambulatory individuals with clinically diagnosed multiple sclerosis underwent supervised progressive resistance training combined with NMES. Balance and mobility were evaluated before and after the intervention using the Berg Balance Scale (BBS), Timed Up and Go Test (TUG), Functional Reach Test (FRT), and Dynamic Gait Index (DGI). Pre- and post-intervention scores were analyzed using appropriate statistical tests with statistical significance set at $p < 0.05$. The trial and intervention details are derived from your study protocol.

Results

Participants demonstrated improvements in all clinical outcome measures following the intervention. Mean Berg Balance Scale scores increased from 44.8 to 50.8, Functional Reach Test values increased from 22.8 cm to 28.8 cm, Dynamic Gait Index scores improved from 18.2 to 21.2, while Timed Up and Go duration decreased from 15.3 seconds to 11.7 seconds following treatment. These findings indicate improvements in postural stability, dynamic balance, gait performance, and functional mobility after progressive resistance training combined with NMES.

Conclusion

Progressive resistance training combined with neuromuscular electrical stimulation appears to be an effective physiotherapy intervention for improving balance and functional mobility in ambulatory individuals with multiple sclerosis. Larger multicentre studies with long-term follow-up are warranted to confirm these findings.

Introduction

Multiple sclerosis (MS) is a chronic, immune-mediated disorder of the central nervous system characterized by inflammatory demyelination, axonal degeneration, and progressive neurological dysfunction. It is among the leading causes of non-traumatic neurological disability in young and middle-aged adults and affects millions of individuals worldwide. The disease frequently presents between the second and fifth decades of life and has a greater prevalence among women. Owing to its heterogeneous clinical manifestations, MS imposes a substantial physical, psychological, social, and economic burden on affected individuals and healthcare systems. Your source describes MS as producing motor, sensory, visual, vestibular, and cognitive impairments that limit functional independence.

Among the numerous impairments associated with MS, balance dysfunction remains one of the most disabling consequences. Efficient postural control depends on the coordinated integration of vestibular, visual, and somatosensory inputs with adequate neuromuscular responses. Demyelinating lesions within the central nervous system disrupt these pathways, resulting in impaired sensory integration, delayed motor responses, muscle weakness, impaired proprioception, and gait instability. Consequently, individuals with MS experience reduced mobility, increased fall risk, decreased confidence during walking, and reduced participation in activities of daily living. These mechanisms and clinical features are described in your thesis.

Balance impairment affects functional independence and quality of life and is therefore a major target of physiotherapy intervention. Exercise-based rehabilitation aims to enhance muscular strength, improve neuromuscular coordination, optimize postural control, and promote neuroplasticity. Progressive resistance training has consistently demonstrated benefits in muscle strength, walking ability, functional mobility, and postural stability in individuals with MS. According to the thesis, the addition of neuromuscular electrical stimulation may further enhance motor-unit recruitment and voluntary muscle activation, potentially facilitating functional improvement.

Neuromuscular electrical stimulation has become an increasingly valuable adjunct to conventional rehabilitation because it can activate skeletal muscles even when voluntary activation is compromised. Repeated electrically evoked contractions may improve muscle recruitment, increase strength, and augment motor learning. When combined with progressive resistance exercises, NMES may produce additive effects by increasing training intensity while enhancing neuromuscular activation.

The randomized controlled trial underlying this manuscript evaluated rehabilitation approaches for balance in ambulatory individuals with MS using standardized outcome measures including the Berg Balance Scale, Timed Up and Go Test, Functional Reach Test, and Dynamic Gait Index. These measures capture complementary aspects of static balance, dynamic balance, gait, and functional mobility.

While the parent trial compared resistance training with NMES against vestibular rehabilitation, the present manuscript focuses specifically on the resistance training with NMES group to provide a detailed evaluation of the intervention's pre- to post-treatment effects. This secondary analysis aims to provide clinicians with a focused understanding of the potential benefits of this intervention for ambulatory individuals with MS. It is based on the RT + NMES intervention and outcome data reported in your study.

MATERIALS AND METHODS

Study Design

This study is a secondary analysis of the resistance training with neuromuscular electrical stimulation (RT + NMES) arm of a randomized controlled trial that investigated rehabilitation interventions for improving balance in individuals with multiple sclerosis (MS). The present analysis specifically evaluates the pre- to post-intervention changes following RT + NMES.

Study Setting

The parent randomized controlled trial was conducted in the Department of Neurology, Pacific College of Physiotherapy, Pacific Medical University, Udaipur, Rajasthan, India, over a period of 12 months. Ethical approval was obtained from the Institutional Ethics Committee of Pacific Medical University before participant recruitment (Approval No. PMU/IEC/MPT/2025/44). All participants provided written informed consent before enrollment.

Participants

Individuals diagnosed with multiple sclerosis by a neurologist were screened according to predefined eligibility criteria. Participants meeting the inclusion criteria were recruited through convenience sampling and subsequently randomized in the parent trial. The present manuscript includes only participants allocated to the RT + NMES group who completed the intervention protocol. Thirty participants completed the parent study, with fifteen in the RT + NMES group analyzed here.

Eligibility Criteria

Inclusion Criteria

Participants were eligible if they:

1. Had a confirmed diagnosis of multiple sclerosis by a neurologist.
2. Were ambulatory and able to participate in supervised physiotherapy.
3. Were medically stable.
4. Were willing to participate and provide written informed consent.

Exclusion Criteria

Participants were excluded if they had:

1 Other neurological disorders affecting balance.
2 Severe orthopedic or cardiopulmonary conditions limiting exercise.
3 Contraindications to neuromuscular electrical stimulation.
4 Cognitive impairment prevents compliance with instructions.
5 Recent MS relapse or unstable medical condition.

Randomization

In the parent randomized controlled trial, participants were randomly assigned using a computer-generated random allocation sequence. Equal allocation was maintained between intervention groups to reduce allocation bias.

Intervention

Progressive Resistance Training with Neuromuscular Electrical Stimulation

Participants underwent a supervised progressive resistance training program combined with neuromuscular electrical stimulation.

The resistance training program targeted the major lower-limb muscle groups responsible for postural stability and gait. Exercises were progressed according to participant tolerance using the principles of progressive overload. Exercise intensity and resistance were gradually increased throughout the intervention period while maintaining correct technique.

Neuromuscular electrical stimulation was applied to selected lower-limb muscles immediately before or during strengthening exercises to enhance motor-unit recruitment and facilitate neuromuscular activation. Electrical stimulation intensity was adjusted individually to achieve a strong yet comfortable visible muscle contraction while ensuring participant safety and comfort.

All treatment sessions were supervised by qualified physiotherapists to ensure adherence, monitor exercise performance, and minimize adverse events.

Outcome Measures

Outcome measures were assessed before and after completion of the intervention by trained assessors.

Berg Balance Scale (BBS)

The Berg Balance Scale is a 14-item clinical assessment evaluating static and dynamic balance during functional activities. Scores range from 0 to 56, with higher scores indicating better balance.

Timed Up and Go Test (TUG)

The Timed Up and Go Test evaluates functional mobility by measuring the time required to stand from a chair, walk three metres, turn, return, and sit down. Lower completion times indicate better mobility.

Functional Reach Test (FRT)

The Functional Reach Test measures the maximum forward reaching distance while maintaining a stable standing posture and is an indicator of dynamic balance and limits of stability.

Dynamic Gait Index (DGI)

The Dynamic Gait Index assesses gait performance under varying functional conditions, including changes in speed, head movements, obstacle negotiation, and stair climbing. Higher scores indicate superior dynamic gait performance.

These outcome measures were selected because they are valid and reliable clinical tools for evaluating balance and mobility in individuals with multiple sclerosis and were used throughout the parent trial.

Results

Participant Flow

Thirty participants diagnosed with multiple sclerosis completed the parent randomized controlled trial. Fifteen participants who received progressive resistance training combined with neuromuscular electrical stimulation (RT + NMES) were included in this secondary analysis. All participants completed the intervention protocol, and no major adverse events were reported during the study period.

Participant Characteristics

The mean age distribution demonstrated that most participants belonged to the 40–50-year age group (46.6%), followed by 30–40 years (33.3%) and 20–30 years (20%). The RT + NMES group included eight males (53.3%) and seven females (46.7%), indicating a balanced sex distribution. Occupational characteristics showed that businessmen represented the largest proportion of participants (40%), followed by housewives (20%), with retired individuals, farmers, and salaried employees each accounting for 13.3%.

Table 1. Baseline Characteristics of Participants (RT + NMES Group)

Characteristics	Value
Number of participants	15
Mean age group	Majority 40–50 years
Male	8 (53.3%)
Female	7 (46.7%)

Balance Outcomes

Following completion of the intervention, participants demonstrated improvement in all outcome measures evaluating balance and functional mobility.

The mean Berg Balance Scale score improved from 44.8 ± 1.4 before treatment to 50.8 ± 1.4 after treatment, indicating improved static and dynamic balance.

The Timed Up and Go Test improved from 15.3 ±

0.5 seconds to 11.7 ± 0.5 seconds, reflecting enhanced functional mobility and walking performance.

Functional Reach Test values increased from 22.8 ± 0.7 cm to 28.8 ± 0.7 cm, demonstrating improved limits of stability.

Dynamic Gait Index scores improved from 18.2 ± 1.2 to 21.2 ± 1.2, suggesting better gait adaptability and dynamic postural control. These values are reported in your manuscript.

Table 2. **Pre- and Post-Intervention Outcomes**

Outcome measures	Pre-Intervention	Post-Intervention
Berg Balance Scale	44.8 ± 1.4	50.8 ± 1.4
Timed Up and Go (seconds	15.3 ± 0.5	11.7 ± 0.5
Functional Reach Test (cm)	22.8 ± 0.7	28.8 ± 0.7
Dynamic Gait Index	18.2 ± 1.2	21.2 ± 1.2

Interpretation of Findings

Progressive resistance training combined with neuromuscular electrical stimulation resulted in clinically meaningful improvements in balance and functional mobility.
The increase in Berg Balance Scale scores suggests improved postural stability during functional activities. Improvement in the Functional Reach Test indicates enhanced limits of stability and better dynamic balance.
Reduction in Timed Up and Go duration demonstrates improved mobility, faster transitional movements, and increased walking efficiency.
Similarly, the increase in Dynamic Gait Index scores indicates improved gait adaptability during functional tasks requiring changes in walking speed, obstacle negotiation, and head movements.

Clinical Significance

From a clinical perspective, the observed improvements suggest that progressive resistance training combined with NMES may enhance neuromuscular activation, lower-limb strength, postural control, and functional performance in ambulatory individuals with multiple sclerosis.
Although this secondary analysis focuses on a single intervention arm, the consistent improvement across all four outcome measures supports the potential role of RT + NMES as an effective rehabilitation strategy in physiotherapy management of MS.

Discussion

The present secondary analysis evaluated the effectiveness of progressive resistance training combined with neuromuscular electrical stimulation (RT + NMES) in improving balance and functional mobility among ambulatory individuals with multiple sclerosis (MS). The findings demonstrated consistent improvements across all outcome measures following the intervention, including the Berg Balance Scale (BBS), Timed Up and Go Test (TUG), Functional Reach Test (FRT), and Dynamic Gait Index (DGI). These results suggest that RT + NMES may be an effective rehabilitation strategy for addressing balance impairment and mobility limitations in individuals with MS. The parent study assessed these outcomes before and after intervention using standardized clinical measures.

Balance impairment is a common consequence of MS and arises from the combined effects of muscle weakness, impaired proprioception, vestibular dysfunction, delayed motor responses, and disrupted sensory integration. These deficits contribute to gait instability, reduced functional independence, and an increased risk of falls. As highlighted in your manuscript, rehabilitation strategies that target these impairments are central to physiotherapy management.

The improvement observed in the Berg Balance Scale following RT + NMES indicates enhanced postural control during functional activities. The BBS assesses both static and dynamic balance through tasks such as standing unsupported, reaching, turning, and transferring. An increase in BBS score after intervention suggests that participants were better able to maintain stability while performing everyday functional activities. The reported increase from 44.8 to 50.8 is consistent with an improvement in balance performance within the RT + NMES group.

Similarly, the reduction in Timed Up and Go (TUG) time reflects improved functional mobility. The TUG is widely used to evaluate transitional movements, walking speed, turning ability, and dynamic balance. Faster completion times after intervention indicate improved lower-limb function and movement efficiency. In the present study, the mean TUG time decreased from 15.3 seconds to 11.7 seconds following RT + NMES, suggesting clinically meaningful improvement in mobility.

Improvement in the Functional Reach Test (FRT) further supports the effectiveness of the intervention. The FRT measures the maximum distance an individual can reach forward while maintaining a stable base of support and is considered an indicator of dynamic balance and limits of stability. The increase in FRT values after treatment suggests enhanced trunk control and improved ability to maintain balance during voluntary movements.

The Dynamic Gait Index also improved after the intervention, indicating better gait adaptability during functional tasks such as walking while turning the head, changing walking speed, negotiating obstacles, and climbing stairs. Because these activities closely resemble real-life mobility demands, improvement in DGI scores suggests that RT + NMES may positively influence community ambulation and functional independence.

Several physiological mechanisms may explain these findings. Progressive resistance training increases muscle strength through overload-induced neuromuscular adaptation, improving force production and endurance of the lower-limb musculature. Neuromuscular electrical stimulation may complement these adaptations by increasing motor-unit recruitment, particularly in muscles with impaired voluntary activation. The combination of these interventions may therefore improve muscle performance, postural stability, and movement coordination more effectively than strengthening exercises alone. This explanation is consistent with the rationale presented in your manuscript.

The findings of this analysis are consistent with the discussion presented in the parent manuscript, which relates improvements following RT + NMES to previously published work on resistance training in MS. The manuscript cites studies reporting improvements in muscle strength, walking ability, functional capacity, and balance after progressive resistance training, and proposes that enhanced neuromuscular activation may contribute to better postural control and mobility.

From a clinical perspective, the observed improvements suggest that RT + NMES may be incorporated into comprehensive physiotherapy programs for ambulatory individuals with MS who present with balance deficits and reduced functional mobility. Because the intervention targets muscle performance and neuromuscular activation, it may complement other rehabilitation strategies aimed at improving sensory integration, endurance, or task-specific balance training. The improvements across multiple outcome measures indicate potential benefits in several domains of function rather than a single aspect of mobility. This interpretation aligns with the overall conclusions of your manuscript.

The present analysis has several strengths. It uses standardized clinical outcome measures that are commonly employed in neurological rehabilitation, allowing comparison with other studies. The intervention was delivered within the framework of a randomized controlled trial, enhancing methodological rigor even though the present paper focuses on a single intervention arm. Furthermore, all participants completed the intervention, and no major adverse events were reported during the study.

Nevertheless, several limitations should be acknowledged. The sample size was relatively small, which may reduce the precision and generalizability of the findings. In addition, the intervention period was limited, and no long-term follow-up was performed to determine whether improvements were maintained over time. As noted in the parent manuscript, future research involving larger multicentre samples, longer intervention durations, and follow-up assessments is needed to strengthen the evidence base for RT + NMES in individuals with MS.

CONCLUSION

This secondary analysis evaluated the effectiveness of progressive resistance training combined with neuromuscular electrical stimulation (RT + NMES) in ambulatory individuals with multiple sclerosis. Improvements were observed across all measured outcomes, including the Berg Balance Scale, Timed Up and Go Test, Functional Reach Test, and Dynamic Gait Index following the intervention. These findings suggest that RT + NMES may enhance postural stability, dynamic balance, gait performance, and functional mobility in this population. The intervention and outcome measures are those reported in your study.

The observed improvements support the integration of progressive resistance training with NMES into physiotherapy rehabilitation programs for ambulatory individuals with MS. However, because this analysis is based on a relatively small sample and short intervention period, larger multicentre randomized trials with longer follow-up are required to confirm the long-term effectiveness and clinical applicability of this intervention.

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