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The Role of Artificial Intelligence and Robotics in the Rehabilitation of Multiple Sclerosis: A Review

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Abstract

Background
Multiple Sclerosis (MS) is a chronic auto-immune disease of the central nervous system. MS is one of the most frequent causes of neurological disability in young adults, affecting cognitive, motor, sensory, and emotional functions.
Aim
This review aims to point out the possible more effective new approach of MS treatment plan including rehabilitation and technology.
Material and Methods
A narrative literature review was conducted based on systematic reviews, meta-analyses, and experimental studies identified through searches of the PubMed and Google Scholar databases.
Results
The use of technology in the rehabilitation of patients with MS can minimize severe complications by improving functional performance, mobility, respiratory efficiency, and overall quality of life.
Conclusions
The future of MS rehabilitation will likely depend on the integration of personalized multidisciplinary care with emerging technologies aimed at maximizing functional independence, neuroplasticity, and long-term quality of life.

Keywords: Multiple Sclerosis, Rehabilitation, Artificial Intelligence, Robotics

1. Introduction

Multiple Sclerosis (MS) is a chronic and progressive inflammatory-demyelinating disease of the central nervous system.
Exact etiology of this disease remains unknown, although it is known for its multifactorial pathogenesis involving genetic, immunological, and environmental factors. It is well established that the course of the disease involves demyelination, accompanied by axonal damage and limited remyelination due to oligodendrocyte injury (Polman et al. 2011).
The clinical course is highly variable owing to the multifocal and disseminated nature of the condition. The first symptoms usually manifest between the ages of 20 and 40.

Studies have shown a well-established female predominance in central nervous system demyelinating disorders, with an overall sex ratio of 3:1 in MS (Ind et al. 2026).

MS is one of the most frequent causes of neurological disability in young adults, affecting cognitive, motor, sensory, and emotional functions. Worldwide, the number of patients is approximately 1,89 million (Khan et al. 2025), and it stands as the leading cause of non-traumatic disability among young adults.

Progressive disability during MS represents one of the greatest challenges in contemporary neurology and rehabilitative medicine. The advanced stage of the disease defined by an accumulation of neurological deficits that impact mobility, cognitive functions, and autonomic functions demand a modified algorithm that extends beyond conservative treatment.

This narrative literature review presents an analysis of rehabilitation options in advanced MS based on current evidence from systematic reviews, meta-analyses, and experimental studies. Relevant articles published in English were identified through searches conducted in the PubMed and Google Scholar databases using keywords related to advanced MS rehabilitation, physiotherapy, and technology-assisted interventions. Emphasis was placed on recent and up-to-date publications concerning rehabilitation strategies and supportive technologies in advanced MS.

2. Types of Multiple Sclerosis

The course of MS is characterized by its variable way of evolution, which presents as different clinical forms of evolution, such as relapsing-remitting, secondary progressive, primary progressive, clinically isolated syndrome or radiologically isolated syndrome (Katz Sand et al. 2015).

The most common is the relapsing-remitting form of MS (RRMS), which occurs in 70–80% of cases. Its defining feature is the frequency of relapses associated with the appearance of new neurological symptoms or the worsening of existing ones and remissions, during which symptoms subside. The duration of a relapse could range from 24 hours to even several days, weeks, or even months.

The primary-progressive form of MS (PPMS) occurs in 15–20% of patients and is characterized by a gradual progression of symptoms without distinct relapses.

Another form is secondary-progressive MS (SPMS), which is preceded by RRMS and manifests as a steady progression of symptoms. It develops after 10–15 years in 30–50% of patients with RRMS, whereas after 25 years, it affects up to 90% of patients.
The next type is the progressive-relapsing form of MS (PRMS), observed in 5% of patients, which is characterized by a steady increase in symptom severity along with acute relapses (Tafti et al. 2024).

3. The Expanded Disability Status Scale

The Expanded Disability Status Scale (EDSS) is a well-established clinical measure to assess disability in MS. This tool is crucial during diagnosis, and it consists of functional system subscales that allow for the evaluation of specific functional systems, as well as the patient's mobility and self-care abilities.
A major issue estimated in this scale is gait dysfunction, which is primarily considered for scoring only above EDSS 3.5. However, a result below EDSS 3.5 may indicate gait disturbances. Apparently, patients with EDSS 2.0–3.5 had gait disturbances, as well as other symptoms such as: fatigue, depression, and quality of life, which occurred frequently than the participants with lower score EDSS < 2.0 ($p < 0.05$).
Considering the above, the EDSS significantly correlated with the measures of walking performance, as well as other measures of fatigue, depression, and quality of life. (Kahraman et al. 2016).

4. Interdisciplinary Approach in Treatment of Multiple Sclerosis

Due to the complexity of MS, numerous studies suggest an interdisciplinary approach to disease management. Evidence shows a positive impact on patients' quality of life, driven by integrated, comprehensive care including a multidisciplinary team.
Integrated care for MS patients should involve neurologists, specialized nurses, physiotherapists, occupational therapists, and psychologists. The complications that occur during the disease extend far beyond motor disability, requiring each professional to bring their unique expertise and skills to patient management.
Furthermore, collaboration with external specialists such as dietitians, speech-language pathologists, social workers, and experts in spasticity, continence, and pain management is highly

recommended. Given the variable outcomes and unpredictable progression of MS, integrating a comprehensive, interdisciplinary approach is crucial.

5. Physical Rehabilitation

5.1 Strength and Resistance Training

Progressive resistance training is an important aspect as a rehabilitation tool in people with MS, as the systematic-reviews evidence indicates its positive effect on muscle strength (Kjølhede et al. 2012). In patients with severe mobility disability, however, the evidence base remains more limited than with individuals with mild to moderate disability as most exercise – training studies in MS have included such patients. Edwards and Pilutti defined severe mobility disability as the need for assistance in ambulation or an EDSS score above 6.0. In their systematic review, 19 articles from 18 studies were included, and 2 of 5 studies on resistance exercise training reported significant improvements. Therefore, in patients with advanced disability, resistance training should be described as a potentially useful therapeutic approach, but that matter still requires further optimization of exercise prescription in this subgroup. (Edwards and Pilutti 2017).

The most direct evidence related to counteracting muscle atrophy comes from a randomized controlled trial by Dalgas et al., although this study included patients with EDSS 3–5.5, not patients with EDSS $\geq$ 6.0. In this trial, 38 patients with MS were randomized either to a 12-week, twice-weekly lower-body progressive resistance training program or to a control group maintaining usual daily activity. The training program consisted of five lower body exercises, with progression. After the intervention, the exercise group showed an increase in mean muscle fiber cross-sectional area and in type II muscle fiber cross-sectional area compared with the control group. Isokinetic strength of the knee extensors and flexors also improved after progressive resistance training (Dalgas et al. 2010). On this basis, it may be stated that resistance training can support the prevention of muscle atrophic changes in MS (Dalgas et al. 2010, Kjølhede et al. 2012, Edwards and Pilutti 2017).

Progressive resistance training has a positive effect on muscle strength, while the evidence for functional capacity, balance, fatigue, quality of life, and mood is less strong but generally positive (Kjølhede et al. 2012). In people with severe mobility disability, conventional resistance exercise training may have benefits for muscular fitness, balance, fatigue, and quality of life (Edwards and Pilutti 2017). Therefore, in patients with advanced MS, resistance training should be presented primarily as an intervention aimed at improving or preserving muscle strength and muscle structure, with possible functional benefits for balance and postural control (Dalgas et al. 2010, Kjølhede et al. 2012, Edwards and Pilutti 2017). Regarding safety, an updated systematic review and meta-analysis found no higher risk of relapses, adverse events, adverse effects, or serious adverse events in exercise-training groups compared with control conditions, which supports the use of appropriately prescribed and supervised exercise training in MS rehabilitation (Learmonth et al. 2023).

5.2 Endurance and Aerobic Training

It has been proven that aerobic and endurance training improves the physical fitness of people with MS. The former involves dynamic exercise that engages large muscle groups and is based on aerobic metabolism. Like endurance training, it is designed to improve cardiorespiratory fitness. Studies based on exercises such as walking, stationary cycling, treadmill running, or ergometer use – performed in continuous or intermittent modes – have demonstrated that they improve the fitness of patients with MS (Andreu-Caravaca et al. 2021). Another meta-analysis showed that aerobic training had the greatest impact on improving quality of life. This is due to increased strength and balance, and thus a lower risk of falls and injuries, as well as better sleep quality. In addition to improved physical fitness, patients' mental well-being also improved. This was associated with the calming effect of acetylcholine via the parasympathetic nervous system, greater independence, and increased resistance to fatigue (Du et al. 2024). The latter parameter was related to age. The younger the patients, the more they experienced improvement in terms of fatigue (Flores et al. 2023). Studies have shown that the optimal duration of physical activity to achieve a reduction in fatigue severity is 150 minutes per week of moderate-intensity activity or 2 sessions of 10–30 minutes of aerobic training and 2 sessions of resistance training (Abou et al. 2025). In addition, it has been proven that exercise is safe for patients. It does not cause side effects or an increase in disease flare-ups (Learmonth et al. 2023). However, the temporary rise in body temperature caused by exercise may exacerbate disease symptoms (Skjerbæk et al. 2013). So-called exercise-induced heat sensitivity (EIHS) is not yet well understood, but it may affect up to 80% of patients. Therefore, it is important to ensure a gradual progression in exercise intensity, monitor heart rate, symptoms, and the condition during exercise, and use various cooling methods as needed (Šilarová et al. 2024).

5.3 Respiratory Rehabilitation

Respiratory rehabilitation is treated as an individualized adjunct to general rehabilitation. Exercises targeting respiratory muscles yield the best results. These involve the use of devices that provide resistance during inhalation and/or exhalation, and sometimes breathing exercises (diaphragmatic, through the nose, and breathing pattern). A meta-analysis demonstrated a positive effect on respiratory muscle strength, lung capacity, and functional fatigue in patients with MS (Chen et al. 2026). An example of a training regimen is presented in an 8-week study involving twice-daily sessions, consisting of three sets of 15 repetitions each, using a threshold resistance training device. Additionally, improvements in quality of life and reductions in fatigue were reported (Ghannadi et al. 2022). Respiratory muscle training may be beneficial for patients with respiratory muscle weakness, shortness of breath, fatigue, ineffective coughing, and recurrent infections (Chen et al. 2026). The exercise methods are safe. However, like most types of physical activity, they require supervision in these patients.

5.4 Functional Training and Proprioception

Functional training (FT) is defined as an approach focused on improving daily mobility by enhancing strength, flexibility, and balance through exercises that mimic activities of daily living. FT emphasizes multi-joint, compound movements that typically do not require specialized equipment, and engage multiple muscle groups. These effects translate into improved coordination and physical performance during everyday activities (Mohammadamini 2026, Pereira et al. 2025). FT is considered particularly important in the physical therapy of patients with MS due to its comprehensive impact on functional performance, strength, and endurance, without the need for access to specialized equipment or gym facilities. Also, this reduces barriers and patient-related concerns regarding physical activity (Adammek et al. 2025). Moreover, FT supports the maintenance of independence and improves quality of life by facilitating activities of daily living, such as household tasks, eating and drinking, or dressing (Döring et al. 2011). From the perspective of daily functioning and independence, gait disturbances remain particularly burdensome and are frequently reported by patients with MS as a limiting consequence of the disease, especially reduced walking speed and decreased walking distance (Pearson et al. 2015). Current evidence confirms the effectiveness of FT in improving overall functional outcomes, including mobility, balance, gait ability, as well as physical fitness, endurance, and strength (Adammek et al. 2025).

For example, a pilot study by Derikx et al. in a group of patients with MS (EDSS $\leq$ 6.5) implemented a 12-week intervention consisting of three 3-hour training sessions per week, followed by an 8-week follow-up period. The sessions included functional training based on functional resistance, endurance, and skills-oriented exercises. The program was found to be feasible for patients. Improvements were observed in functional performance, aerobic capacity, and muscle strength.

However, limitations related to the durability and maintenance of training effects after program completion were noted (Derikx et al. 2022). Further research is required to establish effective FT protocols, often individualized and adapted to the level of disability, as part of physical therapy in patients with MS (Adammek et al. 2025). Patients with MS also exhibit deficits in proprioception (deep sensation), defined as the ability to determine body position in space without visual control. These impairments may result in balance disturbances and reduced motor control (Fling et al. 2014). Therefore, these aspects should be considered when planning and supervising exercises for patients with MS (Halabchi et al. 2017). Proprioceptive exercises in patients with MS, performed in sitting or standing positions, can be combined with coordination and balance training. Additionally, methods aimed at improving balance and stability and reducing fall risk include neuromuscular control training, which can be introduced at early stages of rehabilitation, as well as for example hippotherapy (Kubsik-Gidlewska et al. 2017). Notably, FT may also improve patients' subjective perception of balance, although this does not always correspond to measurable improvements in objective balance assessment scales (Adammek et al. 2025).

6. Technology

6.1 Neuromuscular Electrical Stimulation

In MS, physical activity is an important non-pharmacological tool for managing the various symptoms of the disease. In recent years, numerous rehabilitation methods utilizing modern technologies have been developed to improve motor function. One such solution is neuromuscular electrical stimulation (NMES), which has therapeutic applications and has been approved for use by the U.S. Food and Drug Administration (FDA).

This technique is used, among other things, to reduce pain, limit excessive muscle spasms, and prevent muscle atrophy caused by inactivity. The mechanism of action of NMES involves inducing muscle contractions by stimulating motor nerves. This is achieved through intermittent electrical impulses that are transmitted through the skin and affect superficial skeletal muscles. In the context of MS, the results of some studies suggest that in individuals with higher levels of disability, combining exercise training with NMES may lead to improved physical fitness and a better self-assessment of physical health (Scalia et al. 2024).

In a randomized, double-blind trial, the researchers compared the effects of NMES using narrow- and wide-band pulses. In individuals with MS who had mobility limitations, improvements in both walking endurance and maximum walking speed were observed after six weeks of treatment. However, the effect of NMES on disability-related measures was moderate. In addition to a reduction in the Multiple Sclerosis Walking Scale-12 (MSWS-12 score), a decrease in perceived fatigue measured using the Modified Fatigue Impact Scale (MFIS) was also noted – by an average of 11±17 points in week 7 (with a maximum value of 53) and by 8±16 points in week 11 (Almuklass et al. 2018).

6.2 Robotics

Another research team conducted a systematic review and meta-analysis to assess the impact of gait training using robotic systems in people with MS. The study considered parameters directly related to gait, as well as perceived fatigue, quality of life, and the ability to perform daily activities. Robotic technology enables the lower limbs to be guided according to a correct movement pattern, which facilitates learning to walk by providing appropriate sensory stimuli. The repetitive performance of tasks focused on a specific function supports reorganization processes within the motor cortex, which may translate into improved clinical outcomes in neurological patients. This therapy enhances neuroplasticity by increasing the number of sensory stimuli received. Robotic training also allows for the repeated reproduction of the same, structured movement patterns. The process of walking can be viewed as a series of recurring challenges related to, among other things, maintaining balance, which depends on postural control (Yang et al. 2023).

A study on the rehabilitation of patients with MS compared the effects of robotic-assisted gait training (RAGT) with the results achieved through conventional walking therapy (CWT). The findings indicate that the use of RAGT in individuals with the chronic form of the disease yields results like those observed after conventional training. Immediately after the end of therapy, the group undergoing standard rehabilitation showed significant improvement in most of the assessed gait parameters, whereas in the group using robotic training, improvement was observed in a different set of analyzed indicators. Despite these differences, no clear advantage of either method was demonstrated, as the results of both groups did not differ statistically significantly at any stage of the study. The level of improvement in gait and functional parameters was comparable. It is worth noting that robotic therapy requires less physical effort on the part of the patient and therapist. For this reason, its inclusion in the rehabilitation process may serve as a useful supplement, supporting improved functional ability in individuals with MS (Schwartz et al. 2012).

6.3 Virtual Reality

In an intervention review, Amatya and Khan evaluated the effectiveness of virtual reality (VR) based rehabilitation in patients with MS. The analysis included a total of 33 randomized controlled trials involving 1,294 participants. A moderate beneficial effect of VR-based interventions on upper limb function and quality of life was reported. VR rehabilitation was more effective in improving balance and postural control compared with conventional therapy. However, no significant differences were found between VR and conventional therapy in gait function, cognitive outcomes, or fatigue management (Amatya and Khan 2025).

A study conducted by a team of physicians led by Maggio compared the effectiveness of semi-immersive VR-based rehabilitation, computerized cognitive training (CCT), and traditional cognitive rehabilitation (TCR) on cognitive functioning in 87 patients with MS and mild-to-moderate cognitive impairment. The patients were randomly assigned to three intervention groups: VR, CCT, or TCR. Each group participated in 24 individual rehabilitation sessions conducted regularly three times per week over an 8-week period. The VR group demonstrated significantly greater improvements in executive functions, working memory, and quality of life compared with the CCT and TCR groups ($p < 0.001$). The CCT group showed selective improvement in mood and working memory. However, the overall effectiveness of this method did not differ significantly from that of TCR (Maggio et al. 2026).

A beneficial effect of VR-based rehabilitation in patients with MS was also observed in relation to overall frailty levels. Eighty-three patients were randomly assigned to two groups: treadmill training (TT) and treadmill training augmented with VR (TT+VR). Both groups trained three times per week for six weeks. Assessments were performed at baseline and after 6 weeks, following completion of the intervention. Frailty was assessed using a 40-item Frailty Index (FI). Two exploratory frailty indices were also computed by extracting health-related deficits from the main

FI corresponding separately to the cognitive and physical domains. In both groups, a reduction in frailty levels was observed. However, improvement in the cognitive aspects of frailty was observed only in the TT+VR group, suggesting a potential strategy for mitigating frailty in patients with MS (Zanotto et al. 2025).

6.4 Motor Imagery Brain-Computer Interface

In a hypothesis-generating study, Romagosa et al. evaluated the effectiveness of a rehabilitation approach using a Motor Imagery Brain-Computer Interface (MI-BCI) combined with functional electrical stimulation and a gait-oriented virtual reality avatar in patients with progressive MS. In 24 patients who completed 30 MI-BCI sessions, clinical improvements were observed in walking endurance, mobility/speed, spasticity, and patient-reported outcomes. Walking endurance was assessed using the 6-Minute Walk Test, which showed an increase of 37.3 meters (95% CI: 21.50–53.10, $p < 0.001$). Mobility was evaluated using the Timed Up and Go and Timed 25-Foot Walk tests, which decreased by 15.5% and 16.4%, respectively ($p < 0.001$). Spasticity, assessed using the Modified Ashworth Scale, decreased by approximately 1 point. The beneficial effects were maintained up to 6 months after the end of the intervention (Romagosa et al. 2026).

7. Conclusions

The integration of technology and rehabilitation can minimize severe complications in patients with MS by improving functional performance, mobility, respiratory efficiency, and overall quality of life. Current evidence indicates that interdisciplinary rehabilitation combining conventional physiotherapy with modern technological interventions may positively influence both physical functioning and patient-reported outcomes across different stages of disease progression.

Resistance and functional training demonstrate consistent benefits in muscle strength, mobility, endurance, balance, and postural control, while respiratory rehabilitation may improve respiratory muscle strength, lung capacity, fatigue, and quality of life. The results obtained are consistent with previous observations by other authors, who emphasize the importance of systematic physical activity tailored to the patient's condition, which may play a role in preventing secondary consequences of disability, and supporting the maintenance of the patient's ability to function independently.

Importantly, exercise-based interventions appear safe and are not associated with an increased risk of relapses or serious adverse events when appropriately supervised.

Comprehensive rehabilitation plays a significant role in the care of patients with MS. It should combine traditional physical therapy methods with assistive technologies.

Technological approaches such as NMES, robotic rehabilitation, VR, and personalized body-machine interfaces, such as MI-BCI may further enhance rehabilitation outcomes, particularly in patients with greater disability.

NMES combined with exercise may improve physical performance and reduce fatigue, whereas robotic therapy supports gait retraining and neuroplasticity through repetitive, task-oriented movement and enhanced sensory input. VR-based rehabilitation may increase patient engagement and serve as a valuable complement to conventional therapy, as well as enhance cognitive function, working memory, and patient well-being, which may indicate increased activation of neuroplasticity processes in the central nervous system, although current evidence does not unequivocally confirm its superiority over traditional rehabilitation methods.

Moreover, MI-BCI combined with functional electrical stimulation has shown promising long-term improvements in gait endurance, mobility, spasticity, and patient-reported outcomes.

Despite encouraging findings, substantial heterogeneity persists regarding rehabilitation protocols, intervention intensity, duration, and outcome measures. Many studies remain limited by small sample sizes and insufficient long-term follow-up. Therefore, further high-quality, large-scale randomized controlled trials are required to establish standardized, individualized, and evidence-based rehabilitation strategies for patients with MS.

The future of MS rehabilitation will likely depend on the integration of personalized multidisciplinary care with emerging technologies aimed at maximizing functional independence, neuroplasticity, and long-term quality of life.

Disclosure

Supplementary Materials

Not applicable.

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References

- Abou, L., Murphy, T., Truong, E., & Peters, J. (2025). Meeting physical activity guidelines for persons with multiple sclerosis reduces fatigue severity and impact: a systematic review and meta-analysis of randomized clinical trials. Physical Therapy, 105(6), pzaf046. https://doi.org/10.1093/ptj/pzaf046
- Adammek, F., Gralla, W., Kupjetz, M., Rademacher, A., Zimmer, P., Isenmann, E., & Joisten, N. (2025). Functional exercise training in persons with multiple sclerosis: a systematic review. Journal of Neurology, 272(9), 590. https://doi.org/10.1007/s00415-025-13311-w
- Almuklass, A. M., Davis, L., Hamilton, L. D., Hebert, J. R., Alvarez, E., & Enoka, R. M. (2018). Pulse width does not influence the gains achieved with neuromuscular electrical stimulation in people with multiple sclerosis: double-blind, randomized trial. Neurorehabilitation and Neural Repair, 32(1), 84–93. https://doi.org/10.1177/1545968317753681
- Amatya, B., & Khan, F. (2025). Are virtual reality interventions effective in improving outcomes in people with multiple sclerosis? A cochrane review summary with commentary. NeuroRehabilitation, 57(2), 319–321. https://doi.org/10.1177/10538135251372057
- Andreu-Caravaca, L., Ramos-Campo, D. J., Chung, L. H., & Rubio-Arias, J. Á. (2021). Dosage and effectiveness of aerobic training on cardiorespiratory fitness, functional capacity, balance, and fatigue in people with multiple sclerosis: a systematic review and meta-analysis. Archives of Physical Medicine and Rehabilitation, 102(9), 1826–1839. https://doi.org/10.1016/j.apmr.2021.01.078
- Chen, T., Jin, Y., Jiang, N., Lu, J., Wei, M., Huang, H., & Wen, Y. (2026). Improving respiratory muscle strength in patients with multiple sclerosis through respiratory muscle training: a systematic review and meta-analysis. PeerJ, 14, e20876. https://doi.org/10.7717/peerj.20876
- Chen, Y., Meng, K., Jiang, G., Xiang, X., Liu, Y., & Yi, Q. (2026). Effects of respiratory muscle training on respiratory function and fatigue in multiple sclerosis: a systematic review and meta-analysis. Multiple Sclerosis and Related Disorders, 107, 106953. https://doi.org/10.1016/j.msard.2025.106953

- Dalgas, U., Stenager, E., Jakobsen, J. K., Petersen, T., Overgaard, K., & Ingemann-Hansen, T. (2010). Muscle fiber size increases following resistance training in multiple sclerosis. Multiple Sclerosis Journal, 16(11), 1367–1376. https://doi.org/10.1177/1352458510377222
- Derikx, T. C. A., Brands, I. M. H., Goedhart, A. T., Hoens, W. H., Heijenbrok-Kal, M. H., & Van Den Berg-Emons, R. H. J. G. (2022). High-volume and high-intensity functional training in patients with multiple sclerosis: a pilot study on feasibility and functional capacity. Journal of Rehabilitation Medicine. Clinical Communications, 5, 2047. https://doi.org/10.2340/jrmcc.v5.2047
- Döring, A., Pfueller, C. F., Paul, F., & Dörr, J. (2011). Exercise in multiple sclerosis – an integral component of disease management. The EPMA Journal, 3(1), 2. https://doi.org/10.1007/s13167-011-0136-4
- Du, L., Xi, H., Zhang, S., Zhou, Y., Tao, X., Lv, Y., Hou, X., & Yu, L. (2024). Effects of exercise in people with multiple sclerosis: a systematic review and meta-analysis. Frontiers in Public Health, 12, 1387658. https://doi.org/10.3389/fpubh.2024.1387658
- Edwards, T., & Pilutti, L. A. (2017). The effect of exercise training in adults with multiple sclerosis with severe mobility disability: A systematic review and future research directions. Multiple Sclerosis and Related Disorders, 16, 31–39. https://doi.org/10.1016/j.msard.2017.06.003
- Flores, V. A., Šilić, P., DuBose, N. G., Zheng, P., Jeng, B., & Motl, R. W. (2023). Effects of aerobic, resistance, and combined exercise training on health-related quality of life in multiple sclerosis: systematic review and meta-analysis. Multiple Sclerosis and Related Disorders, 75, 104746. https://doi.org/10.1016/j.msard.2023.104746
- Fling, B. W., Dutta, G. G., Schlueter, H., Cameron, M. H., & Horak, F. B. (2014). Associations between proprioceptive neural pathway structural connectivity and balance in people with multiple sclerosis. Frontiers in Human Neuroscience, 8, 814. https://doi.org/10.3389/fnhum.2014.00814
- Ghannadi, S., Noormohammadpour, P., Mazaheri, R., Sahraian, M. A., Mansournia, M. A., Pourgharib Shahi, M. H., Salmasi Fard, A. H., & Abolhasani, M. (2022). Effect of eight weeks respiratory muscle training on respiratory capacity, functional capacity and quality of life on subjects with mild to moderate relapsing-remitting multiple sclerosis: a single-

blinded randomized controlled trial. Multiple Sclerosis and Related Disorders, 68, 104208. https://doi.org/10.1016/j.msard.2022.104208

- Halabchi, F., Alizadeh, Z., Sahraian, M. A., & Abolhasani, M. (2017). Exercise prescription for patients with multiple sclerosis; potential benefits and practical recommendations. BMC Neurology, 17(1), 185. https://doi.org/10.1186/s12883-017-0960-9
- Ind, G., Hashmi, Z., Ahuja, S., Fayad, T., Kahook, Z., Ahmad, R., Batool, S. M., Jiji, K. M., Hudli, H., Hossain, S., Lafi, A., & AbuJlambo, A. (2026). Demyelinating disorders in women: epidemiology, immunology, and clinical implications across MS, NMOSD, and MOGAD. Journal of Neurology, 273, 290. https://doi.org/10.1007/s00415-026-13831-z
- Kahraman, T., Savci, S., Coskuner Poyraz, E., Ozakbas, S., & Idiman, E. (2016). Utilization of the expanded disability status scale as a distinctive instrument for walking impairment in persons with multiple sclerosis with mild disability. NeuroRehabilitation, 38(1), 7–14. https://doi.org/10.3233/NRE-151290
- Katz Sand I. (2015). Classification, diagnosis, and differential diagnosis of multiple sclerosis. Current Opinion in Neurology, 28(3), 193–205. https://doi.org/10.1097/WCO.0000000000000206
- Khan, G., & Hashim, M. J. (2025). Epidemiology of multiple sclerosis: global, regional, national and sub-national-level estimates and future projections. Journal of Epidemiology and Global Health, 15(1), 21. https://doi.org/10.1007/s44197-025-00353-6
- Kjølhede, T., Vissing, K., & Dalgas, U. (2012). Multiple sclerosis and progressive resistance training: a systematic review. Multiple Sclerosis Journal, 18(9), 1215–1228. https://doi.org/10.1177/1352458512437418
- Kubsik-Gidlewska, A. M., Klimkiewicz, P., Klimkiewicz, R., Janczewska, K., & Woldańska-Okońska, M. (2017). Rehabilitation in multiple sclerosis. Advances in Clinical and Experimental Medicine: official organ Wroclaw Medical University, 26(4), 709–715. https://doi.org/10.17219/acem/62329
- Learmonth, Y. C., Herring, M. P., Russell, D. I., Pilutti, L. A., Day, S., Marck, C. H., Chan, B., Metse, A. P., & Motl, R. W. (2023). Safety of exercise training in multiple sclerosis: an updated systematic review and meta-analysis. Multiple Sclerosis Journal, 29(13), 1604–1631. https://doi.org/10.1177/13524585231204459

- Maggio, M. G., Latella, D., Bonanno, L., Di Lorenzo, G., Calabrò, R. S., De Luca, R., Quartarone, A., Mele, A., Russo, M., Bramanti, A., & Bramanti, P. (2026). Comparing the effect of semi-immersive virtual reality, computerized cognitive training, and traditional rehabilitation on cognitive function in multiple sclerosis: a randomized clinical trial. Annals of Clinical and Translational Neurology, 13, 1–17. https://doi.org/10.1002/acn3.70390
- Mohammadamini, A. (2026). What functional training is and why it's important. Biomedical Journal of Scientific & Technical Research, 65(1). https://doi.org/10.26717/BJSTR.2026.65.010133
- Pearson, M., Dieberg, G., & Smart, N. (2015). Exercise as a therapy for improvement of walking ability in adults with multiple sclerosis: a meta-analysis. Archives of Physical Medicine and Rehabilitation, 96(7), 1339–1348.e7. https://doi.org/10.1016/j.apmr.2015.02.011
- Pereira, H. V., Teixeira, D. S., Fisher, J., Fleck, S. J., Helms, E., Ide, B. N., Izquierdo, M., Nedergaard, A., Philips, S., Pinto, R. S., Plotkin, D. L., Turner, A. N., & Schoenfeld, B. J. (2025). International consensus on the definition of functional training: modified e-Delphi method. Journal of Sports Sciences, 43(8), 767–775. https://doi.org/10.1080/02640414.2025.2477393
- Polman, C. H., Reingold, S. C., Banwell, B., Clanet, M., Cohen, J. A., Filippi, M., Fujihara, K., Havrdova, E., Hutchinson, M., Kappos, L., Lublin, F. D., Montalban, X., O'Connor, P., Sandberg-Wollheim, M., Thompson, A. J., Waubant, E., Weinshenker, B., & Wolinsky, J. S. (2011). Diagnostic criteria for multiple sclerosis: 2010 revisions to the McDonald criteria. Annals of Neurology, 69, 292–302. https://doi.org/10.1002/ana.22366
- Scalia, M., Borzuola, R., Parrella, M., Giannoni, P., Leonardi, L., Di Russo, C., Ferlazzo, E., & Ranieri, A. (2024). Neuromuscular electrical stimulation does not influence spinal excitability in multiple sclerosis patients. Journal of Clinical Medicine, 13(3), 704. https://doi.org/10.3390/jcm13030704
- Schwartz, I., Sajin, A., Moreh, E., Neeb, M., Eitan, S., Kandel, L., & Katz-Leurer, M. (2012). Robot-assisted gait training in multiple sclerosis patients: a randomized trial. Multiple Sclerosis, 18(6), 881–890. https://doi.org/10.1177/1352458511431075
- Sebastián-Romagosa, M., Cho, W., Ortner, R., Sieghartsleitner, S., Guger, M., von Oertzen, T. J., Meuth, S. G., Laureys, S., Allison, B. Z., & Guger, C. (2026). Toward brain-computer

interface motor rehabilitation for people with multiple sclerosis. Frontiers in Medicine, 12, 1661972. https://doi.org/10.3389/fmed.2025.1661972

- Skjerbæk, A. G., Møller, A. B., Jensen, E., Vissing, K., Sørensen, H., Nybo, L., Stenager, E., & Dalgas, U. (2013). Heat sensitive persons with multiple sclerosis are more tolerant to resistance exercise than to endurance exercise. Multiple Sclerosis (Houndmills, Basingstoke, England), 19(7), 932–940. https://doi.org/10.1177/1352458512463765
- Šilarová, A., Hvid, L. G., Hradílek, P., & Dalgas, U. (2024). Exercise-induced heat sensitivity in patients with multiple sclerosis: definition, prevalence, etiology, and management - a scoping review. Multiple Sclerosis and Related Disorders, 90, 105827. https://doi.org/10.1016/j.msard.2024.105827
- Tafti, D., Ehsan, M., & Xixis, K. L. (2024). Multiple sclerosis. In StatPearls. StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK499849/
- Yang, F. A., Lin, C. L., Huang, W. C., Wang, H. Y., Peng, C. W., & Chen, H. C. (2023). Effect of robot-assisted gait training on multiple sclerosis: a systematic review and meta-analysis of randomized controlled trials. Neurorehabilitation and Neural Repair, 37(4), 228–239. https://doi.org/10.1177/15459683231167850
- Zanotto, T., Galperin, I., Pradeep Kumar, D., Mirelman, A., Yehezkyahu, S., Regev, K., Karni, A., Schmitz-Hübsch, T., Paul, F., Lynch, S. G., Akinwuntan, A. E., He, J., Troen, B. R., Devos, H., Hausdorff, J. M., & Sosnoff, J. J. (2025). Effects of a 6-week treadmill training with and without virtual reality on frailty in people with multiple sclerosis. Archives of Physical Medicine and Rehabilitation, 106(2), 187–194. https://doi.org/10.1016/j.apmr.2024.09.010