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Review article

Evaluating Motor Deficits in Multiple Sclerosis Using Jump and Hop Tests: A Review of Current Evidence

[1,*]Eva Žura, [1]Adis Burzić, [2]Erik Paulin, [2,*]Žiga Kozinc

[1]Department of Neurology, University Medical Centre Ljubljana, Ljubljana, Slovenia
[2]University of Primorska, Faculty of Health Sciences, Izola, Slovenia
*Correspondence: ziga.kozinc@fvz.upr.si

Abstract

Multiple sclerosis (MS) is a chronic neurological disease that often leads to subtle motor impairments even in early stages. Traditional clinical assessments may fail to detect these early deficits. Jump and hop tasks, requiring complex neuromuscular coordination, have emerged as promising functional assessments in neurological populations. This review aims to synthesize current evidence on the use of jump- and hop-based assessments to evaluate motor performance in people with MS (pwMS). A systematic search of PubMed and Scopus was conducted in April 2025. Studies were included if they involved pwMS, used jump or hop tasks, and reported performance, kinetic, or kinematic outcomes. Nine studies met inclusion criteria. Countermovement jumps (CMJ) were most frequently used and consistently detected motor deficits in pwMS, including reduced flight time, jump height, and power output. Single-leg CMJ tests identified asymmetries correlated with disability scores. Bipedal hops revealed impaired coordination and anticipatory control. One study assessed motor fatigability through repetitive jumping, while another evaluated the patient experience of sensor-based jump testing. Jump and hop assessments provide potentially sensitive, non-invasive tools for detecting early motor impairments in MS. They offer potential for improving clinical monitoring and guiding individualized rehabilitation strategies.

Keywords: neuromuscular assessment, functional mobility, countermovement jump, motor fatigability, asymmetry detection

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Introduction

Multiple sclerosis (MS) is a progressive, inflammatory, and degenerative disease of the central nervous system (Compston and Coles, 2008; Garg and Smith, 2015). In the brain and spinal cord, there is damage and loss of axons (Garg and Smith, 2015), as well as the spread of demyelinating plaques (Reich et al., 2018). People with MS may report a wide range of symptoms in their medical history, such as sensory loss, paraesthesia, visual disturbances, weakness in the upper and/or lower limbs, facial muscle weakness, ataxia, dizziness, paroxysmal symptoms, heat sensitivity, pain, urological problems, and fatigue (Hauser and Cree, 2020). The disease manifests in various forms. It most commonly begins as a clinically isolated syndrome (CIS), which causes symptoms such as visual problems, tingling, difficulties with walking and balance, altered muscle tone, fatigue, muscle weakness, urinary disturbances, and dizziness (Milo and Miller, 2014; Fisniku et al., 2008). Later, the disease may progress to relapsing-remitting MS (RRMS), characterized by periods of relapses and remissions. A relapse leads to a worsening of the individual's general condition and affects autonomic, sensory, cognitive, and motor functions (Doshi and Cathaway, 2016; Rovaris et al., 2006). Within 10–15 years, RRMS usually develops into secondary progressive MS (SPMS), which is no longer characterized by relapses but instead shows a constant worsening of symptoms (Klineova and Lubin, 2018). About 10–20% of individuals develop the rarest form, primary progressive MS (PPMS), which is marked by gradual worsening from the onset (Compston and Coles, 2008).

The disease brings with it numerous symptoms and requires a multidisciplinary approach that, in addition to a neurologist, usually includes specialized nurses, physiotherapists, occupational therapists, speech therapists, and psychologists (Feinstein and Freeman, 2015; Uygunoglu et al., 2016; Soelberg et al., 2019). Intensive neurophysiotherapy is important both for therapeutic interventions and for precise and meaningful assessment, which forms the basis for identifying the patient's movement disorders, detecting changes, and monitoring the effectiveness of therapeutic procedures. It is reasonable to monitor the individual's motor skills from the time of diagnosis, as a good initial assessment can identify existing issues and help target them effectively. The assessment tools used for this purpose must be reliable, accurate, and sensitive enough to detect subtle changes and deviations from functional movement.

Jumping tasks represent a complex motor skill that integrates muscle strength, coordination, balance, and temporal precision (Klavora, 2000). Unlike isolated strength or balance tests, jump-based assessments require the individual to generate and control rapid force across multiple joints in a sequential and functional manner. These characteristics make jump tasks particularly valuable for detecting subtle neuromuscular impairments that might not be evident in simpler clinical tests. Given the increasing interest in their use for functional assessment, even in older adults (Santos et al. 2022) and populations with neurological conditions (Reina et al., 2018), jumps have emerged as promising tools for evaluating motor performance in people with MS. For example, Geßner et al. (2023) demonstrated that countermovement jumps could detect early motor deficits in individuals with MS even when conventional clinical assessments indicated minimal disability. Despite the growing use of jump-based assessments in neurological research, their application in MS remains relatively underexplored and lacks synthesis. Given the importance of early detection of motor impairments—and the limitations of conventional clinical scales in capturing subtle neuromuscular changes—there is a clear need to evaluate whether and how these complex motor tasks can serve as reliable, sensitive, and functionally meaningful indicators of motor decline. This review therefore aims to consolidate current findings, identify methodological gaps, and assess the potential of jump-based metrics to complement or enhance standard neurological evaluations in people with MS.

Methods

A structured literature search was conducted in April 2025 using PubMed and Scopus databases. The search was independently performed by two authors using the following Boolean search string: ("neuromuscular disorder*"[tiab] OR "neuromuscular disease*"[tiab] OR "motor neuron disease"[tiab] OR "muscular

dystrophy"[tiab] OR "multiple sclerosis"[tiab] OR "Parkinson's disease"[tiab] OR "amyotrophic lateral sclerosis"[tiab] OR "spinal muscular atrophy"[tiab] OR "cerebral palsy"[tiab] OR "Guillain-Barré syndrome"[tiab] OR "myasthenia gravis"[tiab] OR "Charcot-Marie-Tooth disease"[tiab] OR "myopathy"[tiab] OR "neuropathy"[tiab]) AND ("vertical jump" OR "squat jump" OR "countermovement jump" OR "CMJ"[tiab] OR "SJ"[tiab]). No restrictions were applied regarding publication year, but only articles published in English and involving human subjects were considered. Full texts of eligible studies were retrieved and reviewed to confirm inclusion. In addition, backward (reviewing reference list of included papers) and forward (using "cited by" function in Google Scholar) citation tracking was performed on all included articles to identify any additional relevant studies.

After the removal of duplicates, the titles and abstracts were screened for relevance. Studies were included if they met the following criteria: (1) they involved participants with a diagnosis of multiple sclerosis, (2) they applied any type of jump or hop task as a motor assessment tool, and (3) they reported relevant performance, kinematic, or kinetic outcome measures. Full texts of eligible articles were then reviewed to confirm inclusion. Disagreements between the reviewers were resolved through discussion and consensus. Data extraction included study aims, participant characteristics, measurement tools, jump/hop protocols, and key findings. The methodological approach of each study was also noted, including the types of parameters analyzed (e.g., jump height, ground contact time, force, power, asymmetry). A narrative synthesis of results was conducted due to heterogeneity in study designs and outcome measures.

Results

We found nine studies that investigated hops or jumps measurements in different variations, published between 2007 (Pérez et al., 2007) and 2025 (Geßner et al., 2024). Details about individual studies are shown in Table 1, and the study selection process is shown in Figure 1.

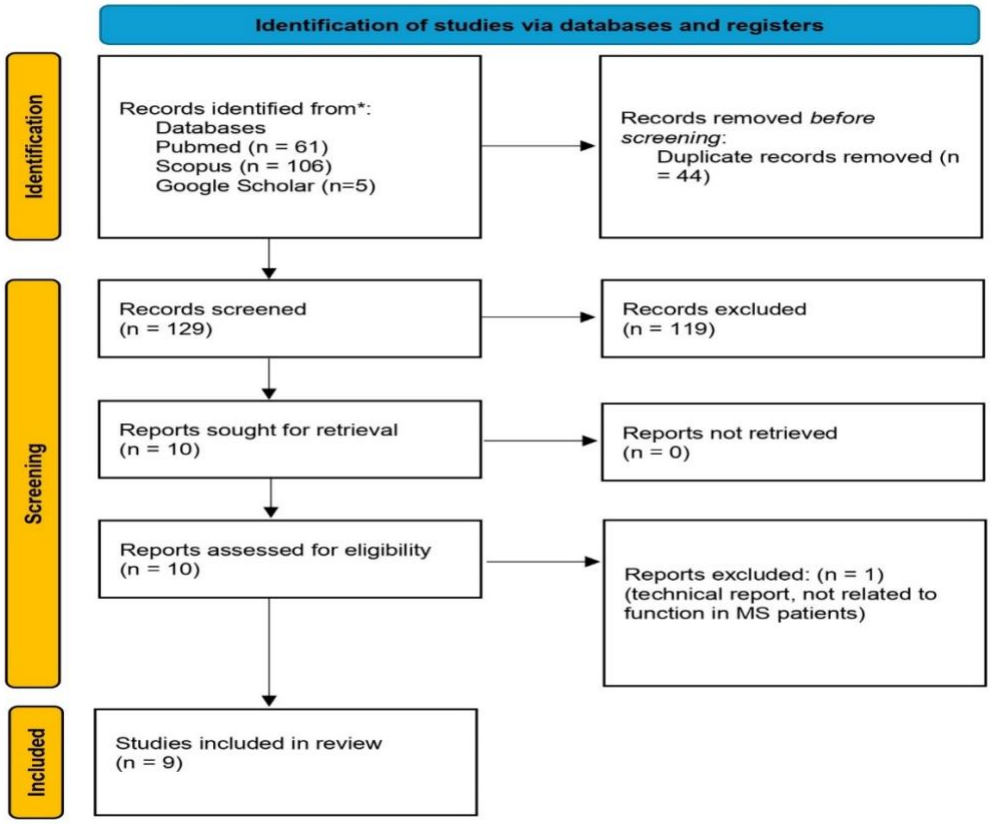

Figure 1. PRISMA flowchart diagram.

Table 1. Details of individual studies included in the review.

Author, Year, Article Title	Purpose	Participant characteristics	Measurement methods	Results /Findings
Geßner et al., 2021 (Quantification of motor fatigue by Jump analysis in people with Multiple Sclerosis)	To evaluate a 10-second jump test to detect muscle fatigue in people with MS.	- 30 individuals with MS (mean age: 33.8 ± 8.1 years; BMI: 23.6 ± 3.1; EDSS: 1.75) - 15 healthy controls (mean age: 39.3 ± 10.8 years; BMI: 24.1 ± 2.8)	Test: As many maximal jumps as possible in 10 seconds Tool: Force plate (AMTI, Accu Power-O) Measured parameters: ground contact time (GCT), reactive strength index (RSI), peak power (PP), push-off impulse (PI), number of jumps Additional: EDSS, neurological assessment, GLMM analysis	MS individuals performed fewer jumps (9.9 ± 2.9) than healthy controls (12.9 ± 2.4). RSI and GCT were negatively associated with functional scores (EDSS). Peak power was negatively associated with cerebellar function in EDSS.
Geßner et al., 2024 (The Association of Age, Sex, and BMI on Lower Limb Neuromuscular and Muscle Mechanical Function in People with Multiple Sclerosis)	To research the association of age, sex, and BMI with muscle mechanical function in people with MS using the Countermovement Jump (CMJ) test.	- 164 individuals with MS (18–65 years, EDSS 0–3.0, able to walk > 500 m unaided, perform basic motor tasks – walking on heels/toes) - 98 healthy controls	Tool: Force plate (AMTI, Accu Power-O), 1000 Hz Analysis: AccuPower Solutions (v1.5.4.2082) Parameters: positive/negative power, force at peak acceleration/deceleration, time to take-off, flight time, jump height, take-off velocity Statistical analysis: mean of 3 jumps, Shapiro Wilk, GLMM, Bonferroni correction, Cohen's d, Spearman correlation	Age, sex, and BMI significantly influenced all jump parameters (flight time, height, power). MS individuals showed poorer jump performance than healthy participants, especially in middle-aged (31–49), normal or overweight, and in both sexes. CMJ can detect subtle motor deficits not visible in standard neurological assessments.
Geßner et al., 2024 (Sensitive Identification of Asymmetries and Neuromuscular Deficits in Lower Limb Function in Early Multiple Sclerosis)	Early detection of neuromuscular deficits and asymmetries in lower limbs using single-leg jump (SLCMJ).	- 126 individuals with MS (mean age: 36.7 ± 8.5 years; 66.7% female; BMI: 24.8 ± 4.6; EDSS: 1.5) - 79 healthy controls (mean age: 37.9 ± 10.9 years; 60.1% female; BMI: 24.2 ± 3.4)	Tool: Force plate (AMTI, 1000 Hz) Test: 3 single-leg CMJ jumps Parameters: push-off time, flight time, landing time, force at zero velocity, GRF, negative/positive/peak power, jump height Analysis: ANCOVA (covariates: age, BMI, sex)	PwMS had shorter flight time, lower force, reduced power, and lower jump height. Greater inter-limb asymmetries in MS, correlated with higher EDSS. SLCMJ is suitable for detecting subclinical deficits and asymmetries in lower limb function in MS.
Geßner et al., 2023 (Countermovement Jumps Detect Subtle Motor Deficits in People with Multiple Sclerosis below the Clinical Threshold)	Using CMJ to identify early motor deficits in people with MS.	- 77 individuals with MS without walking difficulties (age: 35.9 ± 8.8; 70.7% female; BMI:24.6 ± 4.3; EDSS: 1.5) - 22 with MS and motor issues (age: 41.9 ± 10.6; 72.7% female; BMI: 25.6 ± 5.3; EDSS: 3.0) - 33 healthy controls (age: 34.8 ± 7.0; 63.6% female; BMI: 25.0 ± 5.0)	EDSS, GLTEQ questionnaire CMJ Temporal parameters: flight time, braking time, push-off time, FTCTR ratio Kinetics parameters: FZV (N/kg), max force (N/kg), negative/positive power (W/kg), BPIR ratio Performance: jump height (cm)	CMJ proved sensitive in detecting early neuromuscular and motor deficits in MS even at low EDSS scores. CMJ enables identification of eccentric and concentric muscle activity impairments.

Perez et al., 2007 (Effects of a Resistance Training Program in Multiple Sclerosis Spanish Patients: A Pilot Study)	To evaluate the effectiveness of a training program to improve physical fitness in people with MS.	- 24 individuals (9 male, 15 female) - Mean age: 44.4 ± 9.5 years; height: 161.4 cm; weight: 61.5 kg; EDSS: 1–6	Walking speed: zig-zag test over 9 m Arm mobility and orientation: clapping test (CT), dynamic flexibility test (DF) Arm power: medicine ball throw Leg power: vertical jump (VJ) in cm Core strength: abdominal test (AT), back muscles test (BM), leg lifts (LL), Kraus-Weber (KW) test Balance: Flamingo balance test (FB)	Strength training is beneficial for MS rehabilitation; simple strength exercises should be done at home. Individualized exercise programs are recommended.
Kedar et al., 2018 (Comparison Between Common Performance-Based Tests and Self-Reports of Physical Function in People With Multiple Sclerosis: Does Sex or Gender Matter?)	To assess how gender differences affect the relationship between performance tests and self-reported functional outcomes.	- 188 individuals (140 female, 48 male) - MS types: RRMS, SPMS, PPMS, PRMS, CIS; EDSS: 2 (IQR: 1–3)	Tests: modified Canadian aerobic test, grip strength, vertical jump, push-up, curl-up, EQ 5D-3L, 6-min walk test, 9-hole peg test Self-reported activities: rotation, partial sit-up, standing balance, sit-to-stand, forward bend, floor pick-up, trunk twist, bed-making, lifting, changing light bulb, recreational arm/shoulder activities, hand movement activities, transport	Balance tests were highly correlated with daily function. Therapy should be tailored to gender, as physical response may differ.
Kirkland et al., 2017 (Bipedal Hopping Reveals Evidence of Advanced Neuromuscular Aging Among People With Mild Multiple Sclerosis)	Use of bipedal hopping to detect advanced changes in people with mild MS.	- 13 with MS (EDSS ≤ 3.5) - 9 healthy (18–64 years) - 13 older adults (> 70 years)	Tool: instrumented walkway (Protokinetics pressure plate) Tests: bipedal hops, 25-ft walk test (T25FWT) Parameters: T25FWT time, hop length/width, speed, stance time %, mean pressure, CoP path efficiency, variability and asymmetry between legs Analysis: SPSS v21.0	T25FWT: MS group slower than healthy; other speed metrics not significantly different MS group resembled older adults. Linear regression: EDSS linked to hop length. Hop length may be useful for assessing lower limb function in mild MS.
Kirkland et al., 2018 (Bipedal hopping timed to a metronome to detect impairments in anticipatory motor control in people with mild multiple sclerosis)	To assess anticipatory motor control using bipedal hops timed to a metronome.	- 13 with MS (EDSS ≤ 3.5) - 9 healthy (18–64 years) - 13 older adults (> 70 years)	Tool: instrumented walkway (Protokinetics, Zeno electronic walkway) Tests: T25FWT, bipedal hops in rhythm (40 & 60 bpm over 8.5 m), MoCA test Parameters: T25FWT time; hops: step length/width, speed, hop time, stance %, mean pressure, CoP efficiency, variability and asymmetry Analysis: SPSS v 21.0	T25FWT: MS slower than healthy. Shorter hops, higher asymmetry and variability in pressure predicted poorer T25FWT time. Hop delay predicted MoCA only in MS. Shorter hops predicted worse T25FWT time. Bipedal metronome hops can detect mild motor and anticipatory control deficits in MS.
Geßner et al., 2025 (Experiences of People with Multiple Sclerosis in Sensor-Based Jump Assessment)	To evaluate the patient-reported experience of sensor-based jump assessment in pwMS To identify factors influencing these experiences, finding barriers and facilitators for clinical implementation	-175 pwMS (EDSS 0 – 5.5) - age 18-50 - ability to walk more > 500 m and to perform heel stand, toe stand, squats	Tool: portable single force plate (AMTI) Tests: 10 s hop test, CMJ, single-leg CMJ, Patient-Reported Experience Measures (PREM) Questionnaire Parameters: three-dimensional ground reaction forces (Fx, Fy, Fz) and force moments (Mx, My, Mz) Analysis: AccuPower Solutions (Version 1.5.4.2082)	A positive experience with the sensor-based jump assessment by pwMS Able to detect subtle motor changes. Sensor-based jump assessment, especially CMJ, offers a tech-driven way to support early rehabilitation.

Between 24 (Pérez et al., 2007) and 262 (Geßner, Hartmann, Trentzsch, et al., 2024) subjects with a diagnosis of multiple sclerosis participated in the studies. To capture individuals, suitable for early detection of motor deficits, the mean of the subjects on The Expanded Disability Status Scale (EDSS) was a maximum of 2.04 (Kirkland et al., 2017, 2018), indicating minimal disability (Demir, 2022). One study examined the effectiveness of an exercise programme (Pérez et al, 2007), one study looked for sex differences in the relation between tests of physical performance and self-reports about function (Mate et al., 2019), one study looked for sex, age and BMI differences in countermovement jump (Geßner, Hartmann, Trentzsch, et al., 2024), one study looked for -patient-reported experience of sensor-based jump assessment and identified factors influencing these experiences and searched for barriers and facilitators for clinical implementation (Geßner et al., 2025) and one study looked for a suitable measurement tool to detect motor fatigue (Geßner et al., 2021). Three studies searched for a suitable measurement tool to detect early motor deficits in multiple sclerosis (Geßner, Hartmann, Vágó, et al., 2024; Geßner et al., 2023; Kirkland et al., 2017), and one study examined the coordination and anticipation of hopping in a metronome (Kirkland et al., 2018).

Among the included tests, bipedal hops on 8.5-meter-long walkaway (Kirkland et al., 2017, 2018), countermovement jump (Geßner et al., 2023; Geßner, Hartmann, Trentzsch, et al., 2024, Geßner et al., 2025) and vertical jump (Mate et al., 2019; Pérez et al., 2007) were used twice each, while single-leg countermovement jump (Geßner, Hartmann, Vágó, et al, 2024, Geßner et al., 2025) and vertical 10-second hopping (Geßner et al., 2021, Geßner et al., 2025) were used once each. Except in cases where researchers measured only the height of the jump (Mate et al., 2019; Pérez et al., 2007), the measuring tools were force plates (Geßner, Hartmann, Trentzsch, et al., 2024; Geßner, Hartmann, Vágó, et al., 2024; Geßner et al., 2021, 2023, 2025; Kirkland et al., 2017, 2018).

The included measured parameters were time in the air (Geßner, Hartmann, Vágó, et al., 2024; Geßner et al., 2021, 2023) and time on the ground (Geßner, Hartmann, Trentzsch, et al., 2024; Geßner, Hartmann, Vágó, et al., 2024; Geßner et al., 2021, 2023; Kirkland et al, 2017, 2018), force (Geßner, Hartmann, Trentzsch, et al., 2024; Geßner, Hartmann, Vágó, et al., 2024; Geßner, Hartmann, Trentzsch, et al., 2023; Kirkland, et al., 2017, 2018), push-off and landing power (Geßner, Hartmann, Trentzsch, et al., 2024; Geßner, Hartmann, Vágó, et al, 2024; Geßner et al., 2021, 2023), push-off speed (Geßner, Hartmann, Trentzsch, et al., 2024; Geßner, Hartmann, Vágó, et al., 2024; Geßner et al., 2023), jump height (Geßner, Hartmann, Trentzsch, et al., 2024; Mate et al., 2019; Pérez et al, 2007), hop length (Kirkland et al., 2017, 2018) and hopping speed (Kirkland et al., 2017, 2018), three-dimensional ground reaction forces (Fx, Fy, Fz) and force moments (Mx, My, Mz) (Geßner et al., 2025). Kirkland et al. (2017) and Kirkland et al. (2018) additionally looked for inter-hop variability and asymmetries between the lower limbs. Details of the purpose, subjects, measurement tools and findings are summarised in Table.

Discussion

The analysis of the nine included studies demonstrates that jump- and hop-based assessments are effective tools for evaluating motor performance in people with multiple sclerosis (PwMS), even in individuals with minimal or no overt clinical disability. Countermovement jumps (CMJ), single-leg CMJ (SLCMJ) and bipedal hops were used to assess neuromuscular function, revealing consistent impairments in PwMS compared to healthy controls. CMJ was the most frequently used test and showed high sensitivity in detecting subtle motor deficits. Studies by Geßner et al. (2023, 2024) found that individuals with MS had shorter flight times, reduced jump height, and lower push-off force and power compared to healthy controls, even at low EDSS scores. This suggests that CMJ can reveal early neuromuscular dysfunction that may not be captured by standard clinical scales. Single-leg CMJ (Geßner et al., 2024) further enhanced the detection of inter-limb asymmetries, which were significantly greater in PwMS and positively correlated with EDSS scores. This finding underscores the potential of unilateral tests to identify compensatory strategies and early unilateral weakness. These findings

are consistent with prior evidence of pronounced torque asymmetries in the lower limbs already present in individuals with early MS (Kalron et al., 2011).

Bipedal hopping tasks used by Kirkland et al. (2017, 2018) revealed that PwMS performed shorter hops with greater asymmetry and variability, indicating deficits in coordination and anticipatory motor control. Similar gait abnormalities, such as increased variability in step length and timing, have also been reported in early MS, further supporting the presence of coordination deficits even at minimal disability levels (Kalron et al., 2011). Interestingly, PwMS showed hopping patterns more similar to older adults than to age-matched healthy controls, suggesting early neuromuscular aging in MS. The study by Geßner et al. (2021) introduced a fatigue-focused protocol using a 10-second maximal jump test, demonstrating that PwMS performed fewer jumps with lower peak power and reactive strength index. These metrics were negatively associated with EDSS scores, highlighting the relevance of this tast for assessing motor fatigability.

In addition, one early study (Pérez et al., 2007) used vertical jump height to track improvements following resistance training and provided evidence that simple strength exercises may improve jump performance in PwMS. Geßner et al., (2025) found that pwMS had a positive experience with sensor-based jump assessment. It can detect subtle motor changes and, especially through CMJ, supports early, tech-driven rehabilitation. Overall, these findings indicate that jump and hop tests offer valuable, sensitive, and non-invasive means for identifying motor dysfunction in MS. Their ability to detect asymmetries, fatigue, and coordination deficits makes them especially relevant for early-stage patients and for evaluating intervention outcomes. The observed motor deficits align with findings from other studies reporting reduced lower limb performance compared to healthy controls (Ramari et al., 2019). A meta-analysis by Jørgensen et al. (2017) confirms decreased muscle strength, power, and explosive strength, with the latter particularly impaired during rapid concentric contractions. Furthermore, Jonsdottir et al. (2020) highlighted a significantly diminished push-off phase during gait, attributing this to adaptations in neuromuscular control of the ankle.

All studies included in the systematic review identified motor deficits in PwMS across various jump parameters. These deficits manifest as shorter flight time, lower jump height, impaired push-off phase, asymmetries between lower limbs, shorter and more variable jumps, reduced coordination, increased fatigability, and decreased explosive power. A key question remains regarding the underlying pathophysiological mechanisms responsible for these changes. It is most likely a combination of neural and musculoskeletal factors (Maffiuletti et al., 2016). At the central nervous system and crucial sensorimotor pathways, demyelination and axonal loss occur (Reich et al., 2018; Garg & Smith, 2015), simultaneously reducing the capacity for motor unit activation (Ng et al., 2004). Jumping requires complex functional performance involving multiple motor components such as muscle strength and power, coordination, flexibility, and effective neuromuscular control (Cormie et al., 2011). Coordination impairments, frequently presenting as dysdiadochokinesia and ataxia, significantly affect functional abilities, particularly gait, balance, and fall risk (Manto & Marmolino, 2009). Although asymmetries in lower limb muscle performance have been infrequently studied, evidence indicates that greater asymmetry correlates with increased postural sway in mediolateral and anteroposterior directions (Winter, 1995), negatively impacting coordinated movement and balance maintenance during daily activities (Mansfield et al., 2011). Despite the relatively limited number of studies examining jumping tasks in the context of MS, these functional assessments have proven valuable for detecting subtle motor impairments. Their advantage lies in evaluating multiple motor components simultaneously within a functional context, reflecting everyday movement patterns. Moreover, they allow efficient data collection with minimal burden on participants, which is especially important given the characteristic physical and cognitive fatigue in this population (Bakshi, 2023). Such assessments are useful not only for diagnostic evaluation but also for therapy planning, goal setting, and monitoring rehabilitation progress.

Limitations

The search was conducted in two databases. The literature review included a relatively small number of studies due to the inclusion and exclusion criteria. This limits the generalizability of their findings to the broader population of PwMS. The studies examined different forms of jumps and measured different parameters, which hinders direct comparisons between them. The range of EDSS scores among participants varied significantly across studies, indicating a heterogeneous overall sample and consequently diverse motor conditions. Additionally, the studies differed in the measurement tools used to assess jumps, complicating the establishment of a standardized protocol suitable for wider application and potential integration into clinical practice.

Conclusion

A systematic literature review reveals that various types of jumps can serve as an effective assessment tool for detecting subtle motor changes in PwMS. Jumps require a combination of different motor skills and thus represent functional movement. Assessments that evaluate movements resembling those in daily life can contribute to more effective detection of impairments that affect the performance of everyday activities and, consequently, quality of life. This kind of evaluation can enable more specific goal setting, more structured rehabilitation planning and better progress monitoring. There are relatively few studies examining different types of jumps in relation to MS, so further research in this area will be necessary for broader clinical application in the future.

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