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Prevention and Rehabilitation

Pilates for rehabilitation in patients with multiple sclerosis: A systematic review of effects on cognition, health-related physical fitness, general symptoms and quality of life

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ABSTRACT

Objective: The aims of this systematic review is to analyze the effectiveness of Pilates intervention programs on cognitive function, health-related physical fitness, general symptoms, physical function, quality of life, and the impact Pilates can have on activities of daily living in Multiple Sclerosis (MS) patients. This review also aims to provide a synthesis of the most commonly used protocols regarding exercise parameters, such as periodicity and treatment duration.
Data sources: Systematic review of the literature was carried out following the PRISMA guidelines (PROSPERO no. CRD42017070004). A literature search was undertaken for studies that investigated the effects of Pilates training on MS patients, using databases included PubMed, Medline, Scopus and the Physiotherapy Evidence Database (PEDro) up to May 2018.
Study selection: Three researchers independently reviewed the titles and abstract of each article to screen the papers in relation to the inclusion criteria.
Data extraction: Data were extracted by three researchers independently. The eligible articles were read in full and their levels of evidence were evaluated using the PEDro scale.
Data synthesis: Forty-two papers were found during the research phase. Duplicated (n = 23) or incomplete articles (n = 1) were excluded. Studies were also eliminated from the sample based on methodological approach (study design) quality assessment (n = 6). Twelve studies were ultimately selected and analyzed.
Conclusions: The majority of the studies analyzed showed positive results after Pilates training intervention and concluded that Pilates intervention is safe and effective for the treatment of dysfunction of balance, strength, quality of life, cognition, physical performance, walking and posture parameters on MS patients. The articles investigated in this review provide a scientific basis to support Pilates as an option for rehabilitation programs for MS patients.

1. Introduction

Multiple sclerosis (MS) is a chronic immune-mediated, inflammatory and neurodegenerative disease of the central nervous system (Baecher-Allan et al., 2018; Ponath et al., 2018). MS is considered the most common non-traumatic neurological disorder in young adults, especially between 20 and 40 years old, affecting more than 2.5 million people worldwide (Hemmer et al., 2015; Milo and Miller, 2014; Ponath et al., 2018; Silva et al., 2018). A multifactorial cause that includes genetic susceptibility, environmental factors and a presumed autoimmune etiology has been recognized as part of the mechanisms underlying the physiopathology and has been the driving force in treatments (Baecher-Allan et al., 2018; Criste et al., 2014).

MS is a chronic and progressive disease with a heterogeneous and variable neurological clinical disease course. Therefore, MS has a wide range of impairment that characterizes its symptoms and signs, as abnormal balance and gait control, fatigue and limited mobility (Cameron and Lord, 2010; Güner et al., 2015; Hebert et al.,

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2011; Noseworthy et al., 2000). Mobility dysfunction is one of the most common impairments among MS patients and it's estimated that approximately 69% of patients will require a wheelchair approximately 28 years after diagnosis (De Souza and Frank, 2015; Pino et al., 2013).

In addition to motor impairment, this disease also has neurological deficits such as sensory disturbances, spasticity, muscular weakness and visual, cognitive and autonomic dysfunctions (Cameron and Lord, 2010; Güner et al., 2015; Hebert et al., 2011; Noseworthy et al., 2000). Cognitive impairment affects 40–70% of MS patients, specifically the patient's processing speed, memory and attention are the most frequently affected cognitive domains. However, a reduction in information processing and executive functions has also been observed (Beste et al., 2018; Chiaravalloti and DeLuca, 2008; Gallien et al., 2014). Cognitive impairments, allied to physical deficits, negatively impact independence and autonomy on activities of daily living and, consequently, quality of life (Beste et al., 2018; Cameron and Lord, 2010; Göksel Karatepe et al., 2011; Güner et al., 2015; Hebert et al., 2011; Noseworthy et al., 2000).

There is evidence to support physical exercise as a therapeutic strategy to minimize the repercussions of cognitive and physical impairments in patients quality of life (Barry et al., 2016; Houdebine et al., 2017; Snook and Motl, 2009). Physical exercise influences the disease course, exerting positive effects on brain functioning and on different pathophysiological aspects (Barry et al., 2016; Houdebine et al., 2017; Snook and Motl, 2009). The mechanism underlying exercises benefits is associated with the inflammatory process by modulating trophic factors signaling pathways and enhancing endogenous repairing mechanisms (Barry et al., 2016; Houdebine et al., 2017; Snook and Motl, 2009). In this way, physical exercise has anti-inflammatory and neuroprotective effects, providing improvements in muscle strength, cardiorespiratory fitness, mobility, fatigue, and quality of life in MS patients (Barry et al., 2016; Houdebine et al., 2017; Snook and Motl, 2009; Thirumalai et al., 2018).

Pilates is a method of physical exercise that has been used as treatment strategy in MS populations (Di Lorenzo, 2011; Pata et al., 2014). Created by Joseph Pilates, the homonymous method is based on six principles: Centering, Concentration, Control, Breath, Precision, and Fluidity (Di Lorenzo, 2011; Pata et al., 2014). Pilates based exercises are designed for coordination, balance, strength, cardiorespiratory fitness, resistance and flexibility training (Pata et al., 2014; Roh, 2018; Yoon et al., 2016). Pilates is usually performed in functional movements that demand precision of movement, different kinds of synergistic movements (as isometric, eccentric, and concentric muscle contractions), lumbo-pelvic stability and spinal segmental mobility (Pata et al., 2014).

Given the current knowledge about the MS physiopathology and about physical exercise as a therapeutic strategy, this systematic review was conducted to analyze the effectiveness of Pilates intervention programs on cognitive function, health-related physical fitness, general symptoms, physical function, quality of life and its impacts on activities of daily living of Multiple Sclerosis patients and to provide a synthesis of the most commonly used protocols regarding exercise parameters, such as periodicity and treatment duration.

2. Methods

A systematic review of the literature for studies that investigated the effects of Pilates training on Multiple Sclerosis patients was conducted with evidence sourced until May 2018. The review process followed the PRISMA guidelines (Liberati et al., 2009; Mancini et al., 2014) and is registered in the PROSPERO database (no. CRD42017070004).

2.1. Search strategy

Research was conducted using databases including PubMed, the Physiotherapy Evidence Database (PEDro), Medline, SCOPUS and LILACS. The keywords used were *Pilates* and *Multiple Sclerosis* or *Pilates* e *Esclerose Múltipla*. The bibliographical survey was restricted to trials published in English, Portuguese, or Spanish. Three researchers independently reviewed the titles and abstracts of each article to screen the papers in relation to the inclusion criteria. Disagreements between researchers on inclusion criteria were resolved by a fourth reader in a group discussion. The eligible articles were read in full, and their levels of evidence were evaluated using the PEDro scale (de Morton, 2009).

2.2. Study Selection

The following question was investigated: “How does Pilates impact cognitive function, health-related physical fitness, general symptoms, quality of life and activities of daily living of patients with Multiple Sclerosis compared to other interventions or no interventions?”. The author(s), publication year, number of participants, intervention program, exercise type, and outcome measures of all included articles were extracted by three reviewers. The eligibility criteria included:

1. Randomized trials that used Pilates as an intervention to treat multiple sclerosis and reported results in comparison to baseline, other interventions or no interventions.
2. Studies that reported outcomes related to cognitive function, health-related physical fitness, general symptoms, quality of life or activities of daily living of patients with Multiple Sclerosis.
3. Studies involving individuals aged 18 years or older with a diagnosis of Multiple Sclerosis with no restriction on the type of MS.

2.3. Assessment of methodological quality

The PEDro scale consists of 10 items that assess the methodological quality of randomized or almost randomized clinical trials. The validity and reliability of the PEDro scale was assessed previously, as well as the Portuguese version reproducibility (Maher et al., 2003; Shiwa et al., 2011). The final score ranges from zero to ten. Items scored 3 or 4 were considered poor quality and those $\geq$5 moderate to high quality (Da Silva et al., 2018).

3. Results

3.1. Identified studies

Forty-two papers were found in databases. Duplicated (n = 23) or incomplete articles (n = 1) were excluded. Studies were also eliminated from the sample based on methodological approach (study design) and on quality assessment (n = 6). After the abovementioned selection, twelve studies were selected and therefore analyzed (Fig. 1).

3.1.1. Studies quality assessment

Six of the twelve articles were already indexed in PEDro database. The remaining six were analyzed and evaluated by the paper reviewers. Disagreements between the reviewers over the papers' quality assessments were addressed by a fourth reader in a group discussion. Eleven of the research papers presented a score of 5 or

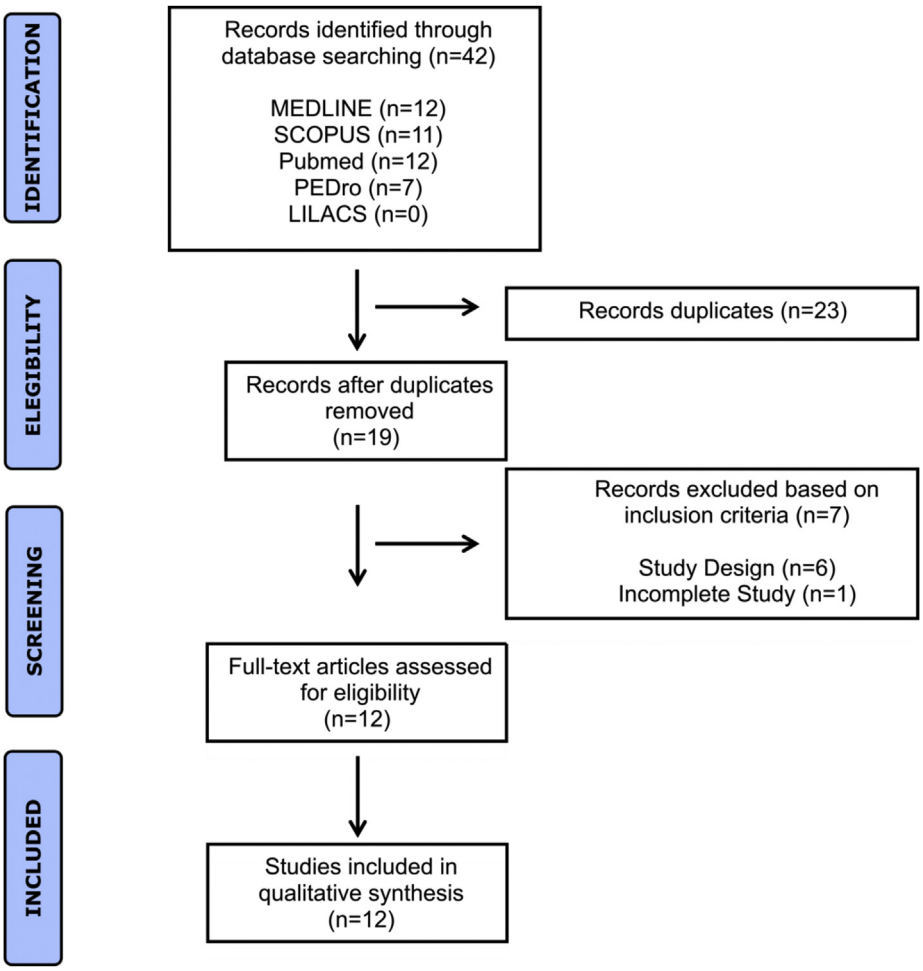

Fig. 1. Flow diagram of studies selection and included in this review.

above, being considered as moderate to high quality articles. One research paper was scored 3 on PEDro scale and therefore classified as poor quality (Da Silva et al., 2018). PEDro scale was not used as exclusion criteria (Table 1).

3.1.2. Characteristics of studies

The analyzed articles' main aims, as well sample size, age, disease duration, Expanded Disability Status Scale (EDSS) information and PEDro score are shown in Table 1.

Table 2 summarizes the main information of the interventions programs in each study: intervention program (frequency, duration, and method), outcomes measures, participants' improvements and the statistical effects on each study, the adverse events, and the conclusion as reported by the authors of each study. In most of the studies included in this review, the results are shown as means and standard deviations for the investigated variables. Synthesis of the quantitative results for all measures with differences statistically significant in the comparison pre- and post-intervention, and/or intra- or intergroup are presented in Supplementary Table 1.

Different parameters were investigated among the studies analyzed, including the effects of the Pilates method on physical fitness as balance, respiratory function or muscle strength, fatigue, posture and postural stability, gait analysis, functionality or functional mobility aspects, cognitive function, sensory interaction impairments, inflammatory profile, pain, or quality of life. Although including an important variety of topics related to physical rehabilitation science, it is important to highlight that the above-mentioned parameters were discussed in a limited number of studies (seven at most for each variable), resulting in limited derived discussions.

3.1.3. Exercise parameters

The number of Pilates sessions underwent by participants ranged from 8 to 36 sessions, performed on a dose regimen which included a frequency of 1–3 times a week, 30–120 min duration period, and 8–20 movement repetitions. The intervention protocols were group-based Pilates sessions, except for the study by Kalron and colleagues (Kalron et al., 2017) and Fox and colleagues (Fox et al., 2016) which ran individualized sessions.

All studies' protocols were based on Clinical Pilates exercises, performed in different postures. Some protocols specified warm-up and cool down phases for each session. The intervention programs included range of motion movements, exercises for stretching, strengthening and balance training.

Progression of the exercise difficulty was based on the acquired ability to maintain the Pilates key elements in response to participant feedback or the gradual increase in intensity (Bulguroglu et al.,

Table 1
Characteristics of the studies included in this review.

Author, year	Study Main Aims	Groups and Sample size	Participants age [mean ± SD years of age].	Disease duration [mean ± SD Years since diagnosis]	Expanded Disability Status Scale (EDSS)	PEDro Scale Rating
Alvarenga-Filho et al. (2016)	"[…] to evaluate the impact of combined exercise training on both fatigue and cytokine profile of T cells from MS patients in response to DA and 5-HT."	Pilates group (MS): n = 08; Healthy Control Group: n = 10; Control group (MS): n = 10.	Pilates group (MS): 41.1 ± 12.9; Healthy control group: 39.7 ± 10.4; Control group (MS): 35.2 ± 7.6.	Pilates group (MS): 10.8 ± 5; Healthy control group: NA; Control group (MS): 8.7 ± 5.3.	≤2.0	5
Bulguroglu et al. (2017)	"To analyze and compare the effects of Mat Pilates and Reformer Pilates methods on balance, core stability, mobility, fatigue and quality of life in patients with MS."	Mat Pilates (MS): n = 12; Reformer Pilates (MS): n = 13; Control group (MS): n = 13.	Mat Pilates (MS): 45 (39.3–49.5); Reformer Pilates (MS):37 (29.5–40); Control group (MS):40 (26–43). #	Mat Pilates (MS): 4.5 (3–13.3); Reformer Pilates (MS):5 (2–10); Control group (MS): 3 (1–8.5). #	≤4.5	5
Duff et al, 2018	"Establish through the Canadian Physical Activity Guidelines for Adults with Multiple Sclerosis, the impact of Pilates on walking ability, quality of life, physical performance […] and daily/ weekly physical activity."	Pilates group (n = 15) Control group (n = 15)	Pilates Group: 45.7 ± 9.4; Control Group: 45.1 ± 7.4	Not described	Not described	7
Fox et al. (2016)	"The primary aim was to compare the effectiveness of a 12-week program of Pilates with relaxation exercise. Secondary aims were to compare a 12-week program of standardized exercises with relaxation and to compare Pilates with standardized exercises […]."	Pilates group (MS): n = 33; Relaxation group (MS): n = 32; Conventional Physical Therapy group (MS): n = 35.	Pilates group (MS): 53.97 ± 9.19; Relaxation group (MS): 53.78 ± 9.72; Conventional Physical Therapy group (MS): 54.60 ± 11.54.	Pilates group (MS): 13.18 ± 10.06; Relaxation group (MS): 12.14 ± 10.68; Conventional Physical Therapy group (MS): 13.91 ± 10.97.	4.0–6.5	8
Guglu-Gunduz et al. (2014)	"[…] to investigate the effects of Pilates on balance, mobility and strength in ambulatory patients with MS."	Pilates group (MS): n = 18; Control group (MS): n = 8.	Pilates group (MS): 36 (29–40); Control group (MS): 36 (27.75–45.25). #	Pilates group (MS): 2 (1.37–7.63); Control group (MS): 1.75 (0.68–3.75). #	≤4	5
Kalron et al., 2017	"[…] to examine the effects of a 12-week Pilates exercise training program on gait and balance in people with multiple sclerosis and compare these results to those of a standard physical therapy intervention program."	Pilates group (MS): n = 22; Control group (MS): n = 23.	Pilates group (MS): 42.9 ± 7.2; Control group (MS): 44.3 ± 6.6.	Pilates group (MS): 11.3 ± 6.9; Control group (MS): 12.4 ± 5.7.	3.0–6.0	7
Küçük et al. (2016)	"To analyze the effects of Pilates on balance, quality of life, body control, cognition and fatigue on MS patients."	Pilates group (MS): n = 11; Control group (MS): n = 09.	Pilates group (MS): 47.2 ± 9.5; Control group (MS): 49.7 ± 8.9.	Pilates group (MS): 14.8 ± 7.4; Control group (MS): 14.2 ± 9.5.	Control Group = 2.8 Pilates Group = 3.2	5
van der Linden et al., 2014	"To evaluate the possibility of implementing a Pilates exercise program for patients with secondary progressive MS who use a wheelchair and analyze the effects of Pilates intervention on posture, sitting stability, breathing capacity, function, fatigue and quality of life."	Pilates group (MS): n = 15	Pilates group (MS): 51 ± 8	Not described	7.0–8.0	5
Marandi et al. (2013) (a)	"Understand the effect of Pilates exercises and aquatic training on the dynamic balance of MS patients."	Pilates group (MS): n = 15; Aquatic training group (MS): n = 15; Control group (MS): n = 15.	20–40 years old	8 ± 2 years##	≤4	5
Marandi et al. (2013) (b)	"To explore, in patients with MS, the repercussions of Pilates exercise and		20–40 years old	8 ± 2 years##	≤4	3

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Table 1 (*continued*)

Author, year	Study Main Aims	Groups and Sample size	Participants age [mean ± SD years of age].	Disease duration [mean ± SD Years since diagnosis]	Expanded Disability Status Scale (EDSS)	PEDro Scale Rating
	aquatic training on the muscular strength."	Pilates group (MS): n = 15; Aquatic training group (MS): n = 15; Control group (MS): n = 15.				
Sisi et al., 2013	"To evaluate the effect, in males with multiple sclerosis, of rebound therapy and Pilates exercise on static and dynamic balances."	Pilates group: n = 15; Rebound therapy (MS): n = 15; Control group (MS): n = 15.	Pilates group: 30.32 ± 8.32; Rebound therapy (MS): 32.21 ± 7.6; Control group (MS): 31.43 ± 7.09	Not described	≤4	6
Soysal Tomruk et al., 2016	"To evaluate the repercussions of modified clinical Pilates exercises on sensory interaction, balance, postural control and fatigue in patients with relapsing-remitting MS and healthy subjects."	Pilates group (MS): n = 11; Healthy control group: n = 12.	Pilates group (MS): 52 (35–66); Healthy control group: 50 (38–65). #	Not described	2.0–5.0	5

results present as median (IQR).
NA: not applicable.
##: nor reported for each group.

2017; Duff et al., 2018; Fox et al., 2016; Guclu-Gunduz et al., 2014; Kalron et al., 2017; Küçük et al., 2016; Soysal Tomruk et al., 2016). The aforementioned key elements are breathing, focus, and placement of the rib cage, shoulder, head, and neck. The majority of the reviewed studies did not include statements about the occurrence of complications, while four of them reported that there were no complications or adverse effects due the Pilates intervention in Multiple Sclerosis patients or in the control group.

3.1.4. *Cognitive function and sensory interaction*

Pilates-based interventions had improved sensory interaction and cognition parameters in Multiple Sclerosis patients (Küçük et al., 2016; Soysal Tomruk et al., 2016). The cognitive function of MS patients was evaluated by Küçük and colleagues (Küçük et al., 2016) by using the Multiple Sclerosis Functional Composite (MSFC), which has a component that assesses cognition with an attention/concentration test (Paced Auditory Serial Addition Test, PASAT). This study was able to find improvements after 8-weeks of Pilates intervention programs on attention function, but not on those participants on a traditional physical therapy program.

Clinical tests of sensory integration showed no differences between the healthy control and patients with Multiple Sclerosis on baseline assessments (Soysal Tomruk et al., 2016). After 10-weeks of a modified Pilates intervention, significant improvement was observed on MS patients, however no comparison to the control group was provided after intervention.

3.1.5. *Health-related physical fitness*

Impacts of Pilates intervention on static and/or dynamic balance were evaluated by different parameters and instruments, including clinical assessments (Berg Balance Scale, Four Square Step Test, Six Spot Step Test, Functional Reach Test, Activities Specific Balance Confidence Scale, Single Leg Stance), and the force platforms, the gold standard instrument. Most studies were able to find improvements on static and/or dynamic balance parameters after the interventions (Bulguroglu et al., 2017; Guclu-Gunduz et al., 2014; Kalron et al., 2017; Küçük et al., 2016; Marandi et al., 2013a; Soysal Tomruk et al., 2016; van der Linden et al., 2014), but some null results were described, like for the postural control (Soysal Tomruk et al., 2016), sitting balance and trunk coordination (Küçük et al., 2016) and balance itself assessed by Berg Balance Scale (Kalron et al., 2017). Additionally, one study found no differences between the Pilates group and control group in balance outcomes assessed by the Fullerton Advanced Balance Scale (Duff et al., 2018).

Only one study investigated the Pilates impact on Forced Vital Capacity and Forced Expiratory Volume in 1 s improvements, and no significant results were registered by Pilates group after 18 sessions (van der Linden et al., 2014).

Muscle strength (assessed by a manual dynamometer and maximum voluntary contraction) (Duff et al., 2018; Guclu-Gunduz et al., 2014; Marandi et al., 2013b) and Timed performance tests (Küçük et al., 2016) had achieved improvements in MS participants who practiced Pilates.

3.1.6. *General symptoms and physical function*

Studies showed improvement in walking speed (2-min and 6-min walking tests) for both groups (Pilates and Physical Therapy) after intervention, as well as on the patient's perceived impact of multiple sclerosis on walking ability (Multiple Sclerosis Walking Scale) (Kalron et al., 2017) and posture, measured by the interscapular distance (van der Linden et al., 2014). However, the positive impact of Pilates protocol on functional mobility, assessed by the Timed Up and Go test, is faced with both positive and

Table 2
Rehabilitation interventions in MS based on papers included in this review.

Author, year	Intervention Program		Outcome measures	Results		Conclusion	Adverse events
	Duration and Frequency	Intervention method		Comparison Pre and Post Intervention	Comparison Between Groups		
Alvarenga-Filho et al. (2016)	24 sessions, 1 h, twice a week, 12 weeks, 8–12 repetitions.	Pilates training combined with aerobic exercise.	Fatigue; Cytokine production; Dopamine (DA), Serotonin [5-hydroxytryptamine (5-HT)] dosage.	Differences statistically significant on fatigue, peripheral levels of TNF-α, IL-22 and IL-6 (All $p < 0.05$).	In MS groups (tMS and utMS), the levels of TNF-α, IL-6, IFN-γ and IL-22 were positively correlated with severity of fatigue at baseline, determined by FSS.	"[…] combined exercise training in MS patients with low neurological disability can help them not only with management of fatigue but also it could have a neuroprotective potential by modulating the responsiveness of T cells to neurotransmitters […]."	Not described
Bulguroglu et al. (2017)	8 weeks, 2 days a week, 1 h or one and half hour	Pilates exercise (Mat or Reformer) or Control group.	Balance, core stability, functional mobility, fatigue severity and quality of life	Statistically significant improvements for all outcome measures for Mat and Reformer Pilates groups ($p < 0.05$). The control group showed statistically significant improvement only in the Physical Health category ($p < 0.05$).[a]	There were statistically significant differences only for core strength between the Mat and Reformer Pilates groups ($p > 0.05$)	"As a result, similar benefits have been seen in patients with MS in Reformer Pilates and Mat Pilates methods. It is believed that both trainings are beneficial for increasing balance, mobility and strength, reducing fatigue severity and developing the quality of life in patients with MS.[…]."	Not described
Duff et al, 2018	Twice a week, 50 minutes, 12 weeks.	Pilates Exercises or Control Group	walking ability, quality of life, functional ability; balance; flexibility; body composition; quadriceps strength, fatigability, voluntary muscular activation, core endurance; and daily/weekly physical activity.	walking ability ($p = 0.01$) and functional ability ($p = 0.03$) were statistically different within groups	There was statistically significant difference in functional ability (TUG) in the Pilates group ($p = 0.03$)	"In conclusion, Pilates is a safe and effective exercise option for improving mobility in individuals with MS. Future studies should compare Pilates therapy with other exercise therapies and evaluate other outcomes important in MS."	No Adverse Effects
Fox et al. (2016)	Pilates: 12 sessions, 30 min, once a week, 12 weeks, 15-min daily home-based exercises; Relaxation: 3 session, one session per month; Conventional Physical Therapy group: 12 sessions, 30 min, once a week, 12 weeks, 15-min daily home-based exercises;	Pilates, standardized exercises, or relaxation.	Mobility, balance, walking speed, functional reach, walking impairment, perceived balance confidence, dual task problem	At 12 weeks, for all outcome measures except the visual analog scale (VAS), there were statistically significant differences among the allocated groups (all $p < 0,05$). At 16 weeks, there was evidence of statistically significant differences among allocated groups for walking speed, lateral functional reach,MSWS-12 score, and ABC score only (all $p < 0,05$).	At 12 weeks Standardized Exercise Group *vs* Relaxation Group: Standardized Exercises did statistically significantly better in walking speed, functional reach, walking impairment and on perceived balance confidence ($p < 0.05$). Pilates Group *vs* Standardized Exercise Group: standardized exercise group was significantly better in walking speed and walking impairment ($p < 0.05$). At 16 weeks Standardized Exercise Group *vs* Relaxation Group: Statistically significant difference in functional reach, walking speed and walking impairment for	"In conclusion, a 12-week period of Pilates led to small, nonsignificant improvements in patient-reported and clinician-rated measures of balance and mobility in comparison with relaxation. These small improvements were not sustained at 1 month after the therapist contact time ceased. Standardized physical therapy exercises led to statistically and clinically meaningful changes in both patient-reported and clinician-rated measures of balance and mobility compared with relaxation, which	There were no reported harms or adverse reactions in any of the participants.

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Table 2 (*continued*)

Author, year	Intervention Program		Outcome measures	Results		Conclusion	Adverse events
	Duration and Frequency	Intervention method		Comparison Pre and Post Intervention	Comparison Between Groups		
					standardized exercise ($p < 0.05$). Pilates Group *vs* Standardized Exercise Group: difference statistically significant on walking impairment for standardized exercise ($p < 0.05$).	remained evident 1 month after the therapist contact time had ceased."	
Guglu-Gunduz et al. (2014)	Pilates group: 16 sessions, 1 h, twice a week, 10 repetitions, 8 weeks. Control group: 16 sessions, twice a week, 10 repetitions, 8 weeks	Pilates or control group (home exercise program)	Balance, confidence in balance, functional mobility and muscle strength	After Pilates, there were improvements statistically significant on balance, mobility, confidence in balance skills while performing daily activities and on muscles strength ($p < 0.05$).	Without groups comparison	"[…] show that an 8-week Pilates training program was effective in improving balance, mobility and strength in patients with MS. Pilates training may be advised for physical therapy programs directed at unbalance and strength loss […]."	Not described
Kalron et al., 2017	Pilates group: 12 sessions, 30 min, once a week, 12 weeks, 15-min daily home-based exercises. Control group: 12 physiotherapy sessions, 30 min, once a week, 12 weeks plus 15-min daily home-based exercises	Pilates or standardized physical therapy	Static balance, gait, fatigue and mobility	Both groups showed improvements statistically significant on balance, gait and mobility (All $p < 0.05$)	There was no difference statistically significant between groups.	"In conclusion, this study presents an alternative rehabilitation program for people with multiple sclerosis. […] this study shows that Pilates is a potential treatment option for people with multiple sclerosis to improve their walking and balance capabilities. However, this approach does not have any significant advantage over standardized physical therapy."	No adverse or harmful events were reported in both groups.
Küçük et al., 2016	16 sessions, 45–60 min, twice a week; 8–10 repetitions	Clinical Pilates or traditional exercise programme	Static and dynamic balance, quality of life, fatigue and cognition, trunk coordination and control, Physical performance, walking performance, depression	In Pilates group static and dynamic balance; physical performance; fatigue; cognition (some parameters) were statistically significant ($p < 0.05$). In control group physical performance (except time to left), walking performance.; cognition (some parameters) were statistically significant ($p < 0.05$).	Improvements on cognition (some parameters) and quality of life in favor of the clinical Pilates group ($p < 0.05$)	"In Multiple Sclerosis treatment, clinical Pilates should be used as a holistic approach by physical therapists."	Not described
van der Linden et al., 2014	18 sessions, 1 h, the first six weeks twice per week, followed by six weeks once a week, 12 weeks.	Pilates Exercises	Sitting stability, sitting posture, pain at the neck, back and upper extremity, fatigue and the impact of MS, Forced Vital Capacity (FVC), Forced	At 12 weeks sitting stability to left ($p = 0.046$); interscapular distance relaxed ($p = 0.026$) interscapular distance upright ($p = 0.004$);	Without comparison groups	"[…] showed that Pilates or core stability exercises are feasible for people with MS who use a wheelchair. Statistically significant improvements compared to the baseline assessments	No adverse events were reported.

			Expiratory Volume in 1 s (FEV 1), function in activities of daily living, and a qualitative assessment on their point of views about Pilates classes.	pain at arms and shoulders ($p = 0.005$); pain at back ($p = 0.005$); physical and psychological impact of Multiple Sclerosis ($p = 0.006$) were statistically significant. In the qualitative analysis, enjoyment of classes was expressed by all, and most people felt that there were benefits from taking part, including social, physical, functional and psychological improvements		were found […]. The qualitative component of this study also confirmed that Pilates exercise classes are possible for wheelchair-users […]. However, it is important to minimize barriers […]. Future appropriately powered controlled mixed method studies […] are warranted"	
Marandi et al., 2013 (a)	36 sessions, 1 h, 3 times a week.	Aquatic training, Pilates exercise or control group.	Dynamic Balance	There were statistically significant difference in dynamic balance at Pilates Group and Aquatic Group ($p < 0,05$).	There were statistically significant difference in dynamic balance between Pilates Group and Control group ($p < 0,05$) and between Aquatic Group and Control: ($p < 0,05$)	"In conclusion, the specialists in the field are recommended to use these exercises as a supplementary treatment along with medicinal treatment plans for MS patients."	Not described
Marandi et al. (2013) (b)	36 sessions, 1 h, 3 times a week.	Aquatic training, Pilates exercise or control group.	Muscular strength	The difference in means for muscle strength in the experimental groups was statistically significant ($p < 0.05$).	Only the mean differences for muscle strength in the Pilates and Aquatic Groups compared to the control group were statistically significant ($p < 0.05$)	"The results of this study demonstrate that the aquatic training and Pilates exercise are among the most effective exercise types for MS patients. Therefore, specialists are advised to suggest these exercise programs as supplements to the medicinal treatment plans for MS patients."	Not described
Sisi et al., 2013	24 sessions, 30 min	Rebound therapy, Pilates exercise or control group.	Static and dynamic balance	Static and dynamic balance only in the Rebound Therapy and Pilates groups were statistically significant ($p < 0.01$).	For both static and dynamic balance, only the mean differences between the Pilates Groups and Rebound Therapy compared to the Control Group were statistically significant ($p < 0.01$).	"Both rebound therapy and Pilates exercises equally improve static and dynamic balancing in patients with MS. However, rebound therapy exercises were found to be more effective in improving dynamic balancing and Pilates exercises were more effective in enhancing static balancing. This could be a result of rebound therapy exercises including more jumps and Pilates exercises being done in a more static position. Therefore, we suggest that both rebound therapy and Pilates exercises can be applied as	Not described

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Table 2 (*continued*)

Author, year	Intervention Program		Outcome measures	Results		Conclusion	Adverse events
	Duration and Frequency	Intervention method		Comparison Pre and Post Intervention	Comparison Between Groups		
						an efficient combination method in the rehabilitation procedures as part of therapy for patients with MS."	
Soysal Tomruk et al., 2016	20 sessions, 1 h, twice a week.	Pilates Exercises or Control Group	Sensory interaction, balance, postural control and fatigue	Improvements statistically significant occurred in the sensory interaction and balance score (foam surface with open eyes) and in fatigue scores (Total, Physical and Cognitive) in Pilates group ($p < 0.05$). There was no analysis for baseline in Control Group.[a]	Without comparison groups	"Ten-week Pilates exercise training that specifically addresses postural control and central integration is effective to improve sensory interaction and to decrease fatigue. Pilates exercises can be applied safely in ambulatory pwMS for enhance sensory interaction and balance and combat fatigue."	Not described

[a] results present as median (IQR).

negative results on performance improvement (Bulguroglu et al., 2017; Duff et al., 2018; Guclu-Gunduz et al., 2014; Kalron et al., 2017; Küçük et al., 2016).

Divergent results emerge from the impact of Pilates on fatigue symptoms in MS patients, independent of the assessment tool used (Modified Fatigue Impact Scale or Fatigue Severity Scale) (Kalron et al., 2017; Küçük et al., 2016; Soysal Tomruk et al., 2016; van der Linden et al., 2014). Alvarenga-Filho and colleagues (Alvarenga-Filho et al., 2016) suggested that reductions of fatigue symptoms may be underlined by the anti-inflammatory effect of exercise, affecting the patient cytokine profile.

There was a decrease in visual analogical scales for pain in the neck, shoulders and back, as well as a decrease in the physical and psychological impact of MS measured by the Multiple Sclerosis Impact Scale-29 after 12 and 18 weeks Pilates intervention sessions in the wheelchair MS patients sample (van der Linden et al., 2014).

3.1.7. *Quality of life and activities of daily living*

Most of Pilates' interventions pointed out positive impact on quality of life (Multiple Sclerosis International Quality of Life Questionnaire). One study showed no differences between the Pilates group and the control group (Multiple Sclerosis Quality of Life—54 instrument) (Duff et al., 2018). No positive impact was detected on depressive symptoms (Beck depression inventory) (Küçük et al., 2016).

The evaluation of the ability to perform the activities of daily living showed improvements in patients that underwent Pilates intervention (Activities specific balance confidence scale) (Guclu-Gunduz et al., 2014), but not for the performance and satisfaction with the performance in activities of daily living assessed by Canadian Occupational Performance Measure (van der Linden et al., 2014).

4. Discussion

Physical exercise practice is essential to manage the disease course and symptoms. MS patients are 2.3 times less engaged in regular physical activities as compared to healthy people, with only 20% of the patients meeting the guideline's recommendations for moderate-to-vigorous physical activity required for adequate physical health maintenance (Uszynski et al., 2016).

The main objective of this systematic review was to assess the effectiveness of Pilates' interventions as exercise programs dedicated to MS patients. Twelve trials were analyzed including the effect of Pilates on cognition, health-related physical fitness, general symptoms, quality of life and activities of daily living of MS patients with EDSS stage up to 8. Based on the available information from seven studies, the participants in the Pilates' groups had 11.01 years of disease duration and the Control groups had 11.04 years.

In accordance to the results analyzed, the Pilates-based interventions could be stated as an option of intervention modality in the Physical Therapy treatment for patients with MS. Its positive and statistically significant benefits were pointed out related to improvements in muscle strength, cognition, sensory function, timed performed tests, walking speed and ability, posture, static and dynamic balance, quality of life, performance in activities of daily living, and reduction of pain and pro-inflammatory cytokines (quantitative measures for each function are described in Supplementary Table 1) (Alvarenga-Filho et al., 2016; Bulguroglu et al., 2017; Duff et al., 2018; Fox et al., 2016; Guclu-Gunduz et al., 2014; Sisi et al., 2013; Kalron et al., 2017; Küçük et al., 2016; Marandi et al., 2013a, 2013b; Soysal Tomruk et al., 2016; van der Linden et al., 2014). There was mixed evidence regarding the effectiveness of Pilates for improving balance, functional mobility and fatigue (Duff et al., 2018; Fox et al., 2016; van der Linden et al.,

2014). No evidence of benefits relating to the respiratory function, depressive symptoms (van der Linden et al., 2014) or fatigability (Duff et al., 2018) was found.

In general, the articles included in this review evaluated the efficacy of Pilates Method as a unique therapy in treatment of MS, in comparison to other therapies, such as combined training, water exercise, rebound therapy, relaxation, conventional Physical Therapy, massage or home exercise program. The outcomes were confronted with baseline and/or control group. Controls groups were composed of MS patients who underwent a different intervention or healthy control subjects not enrolled in any intervention.

Two of the studies did not perform post intervention statistical comparison among Pilates *vs* Control groups. In these cases, studies only reported results regarding the pre- *vs* post-intervention scores on an intragroup analysis (Guclu-Gunduz et al., 2014; Soysal Tomruk et al., 2016). This approach weakens the interpretation about which intervention method has better therapeutic results for MS populations. However, the papers that compared the outcomes between intervention groups report better results on some clinical or biochemical parameters for Pilates groups (Alvarenga-Filho et al., 2016; Duff et al., 2018; Küçük et al., 2016) or no differences on the group's performance and, therefore, providing scientific basis to indicate Pilates as an option for Physical Therapy programs (Sisi et al., 2013; Kalron et al., 2017; Marandi et al., 2013a, 2013b).

An exception is noticed for the study of Fox and colleagues (Fox et al., 2016) which was the only reviewed study that failed to report improvements on balance, mobility, walking speed and ability of the participants on Pilates group, but did reach significant differences for participants on Standard Exercise group. However, the authors affirm that the Pilates exercises used for the intervention did not correspond to the usual exercises used in clinical practice, being less likely to improve balance and gait. In addition, the shorter intervention time per week (30 min/week) and the low attendance to the sessions on Pilates' group, limited to 66% of the entire program, compared to 84%–92% for the other interventions groups, may have limited the participants' functional improvement.

4.1. Duration, intensity and supervision of the exercise programs

The protocols performed in the studies were heterogeneous regarding the periodization and the parameters used. Seven studies investigated in this review performed 12 weeks intervention programs (Alvarenga-Filho et al., 2016; Duff et al., 2018; Fox et al., 2016; Kalron et al., 2017; Marandi et al., 2013a, 2013b; van der Linden et al., 2014), one had 10 weeks (Soysal Tomruk et al., 2016) and four had 8-week duration (Bulguroglu et al., 2017; Guclu-Gunduz et al., 2014; Sisi et al., 2013; Küçük et al., 2016). Among those who performed for 10 or 12 weeks, four studies showed positive effects in all outcomes measures (Alvarenga-Filho et al., 2016; Kalron et al., 2017; Marandi et al., 2013a, 2013b) and three did not have significant improvements in some of the analyzed variables (Fox et al., 2016; Soysal Tomruk et al., 2016; van der Linden et al., 2014), including the one with a 30 min intervention time (Fox et al., 2016). Two out of three studies that implemented 8 weeks of intervention did not obtain significant results in specific outcomes (Guclu-Gunduz et al., 2014; Küçük et al., 2016). Taken together, those results suggest that long-term training seems to be more effective as physical interventions for the clinical impairments of MS compared to short-term therapies.

Pilates exercises were supervised and delivered by qualified Pilates instructors in all studies, and, in 50% of them, the instructors were also Physical Therapists.

5. Limitations of reviewed papers

Limitations detected among the papers analyzed include the range of methodological quality scale (3–8 PEDro score) which may reflect on outcomes and results. In addition, the reduced sample size per group included for statistical analysis (08–35 participants) that could have compromised the reliability of the statistical analysis, despite the low epidemiology of MS. Other limitations include the diversity of the applied protocols regarding the number of sessions and exercise periodization, the low attendance rate in some studies (<75%) or missing information on that criteria, and also the broad range of disability levels (0–8 EDSS score). This last limitation brings important differences in the studies, which were composed by patients who could walk independently, in need of auxiliary devices or in use of a wheelchair. This fact limits the discussions of the Pilates method in distinct phases of multiple sclerosis.

6. Conclusion

The results analyzed support indication for Pilates as a safe and effective rehabilitation modality option in the treatment of patients with MS. There is evidence of the effectiveness of Pilates as a therapeutic modality on specific outcomes such as static and dynamic balance, strength, quality of life, cognition, physical performance, walking and posture parameters. The available results are still mixed regarding Pilates as a targeted treatment for functional mobility deficits and pain, and there is no evidence on the directed effectiveness on Forced Vital Capacity.

The intervention protocols in the studies reviewed are very diverse with a large range of session count (12–36 sessions) and periodization (performed 1 to 3 times a week, for 30–60 min), which causes difficulties in the establishment of an ideal Pilates intervention protocol for MS patients. Therefore, in order to better understand and guide clinical practice, more studies are required to address the recommended training protocol for MS population, mostly the aspects of exercise periodization.

Author declaration

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Declaration of competing interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at

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