Comparative ergospirometric responses to arm-crank and leg-cycle exercise in women with multiple sclerosis: a pilot study

Respuestas ergoespirométricas comparativas al ejercicio de brazos y piernas en mujeres con esclerosis múltiple: un estudio piloto

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Abstract

Objectives: This pilot study aimed to determine whether aerobic capacity differs when assessed using arm-crank ergometry (ACE) and leg-cycle ergometry (LCE) in women with relapsing-remitting Multiple Sclerosis (wwMS) and healthy controls (HC), and to compare the percentage difference in peak oxygen consumption (VO_2peak) between ACE and LCE across groups.
Methods: A descriptive cross-sectional study was conducted involving twenty women: ten wwMS (EDSS range, 2-5) and ten HC, matched for age, body weight, and BMI. All participants completed two separate ergospirometric tests: one using ACE and one using LCE. The variables analysed included VO_2peak, peak mechanical power (Wpeak), respiratory quotient, peak pulmonary ventilation (VEpeak), maximal heart rate (HRmax), and oxygen pulse. The percentage difference between ACE and LCE (ACE/LCE ratio) was calculated for each variable. Data were analysed using the Mann-Whitney U test, with statistical significance set at $p < 0.05$.
Results: Compared with HC, wwMS showed lower VO_2peak ($p = 0.004$ and $p = 0.005$), Wpeak ($p = 0.002$ and $p < 0.001$), HRmax ($p = 0.013$ and $p = 0.003$), and VEpeak ($p = 0.003$ and $p = 0.001$) during the ACE and LCE assessments, respectively. WwMS also exhibited a lower oxygen pulse than HC ($p = 0.005$) during ACE, but not during LCE. The ACE/LCE ratio showed that mechanical power was lower in wwMS compared with HC ($p = 0.045$).
Conclusions: Women with mild to moderate MS exhibit reduced cardiovascular, pulmonary, and muscular capacity, as well as a smaller percentage difference in arm power relative to leg power, suggesting greater impairment of the lower limbs in this population.

Keywords

Exercise testing; multiple sclerosis; neurorehabilitation; physical performance; upper vs lower limbs.

Resumen

Objetivo: Este estudio piloto tuvo como objetivo determinar si la capacidad aeróbica se ve afectada de manera diferente cuando se evalúa mediante ergometría de brazos (ACE) y ergometría de piernas (LCE) en mujeres con Esclerosis Múltiple remitente recurrente (wwEM) y en controles sanas (CS), así como comparar la diferencia porcentual en el consumo de oxígeno pico (VO_2pico) entre ACE y LCE entre los grupos.
Métodos: Se realizó un estudio transversal descriptivo en veinte mujeres: diez wwEM (rango EDSS, 2-5) y diez CS, emparejadas por edad, peso corporal e IMC. Todas las participantes completaron dos pruebas ergoespirométricas independientes: una con ACE y otra con LCE. Las variables analizadas incluyeron VO_2pico, potencia mecánica máxima (Wpico), cociente respiratorio, ventilación pulmonar pico (VEpico), frecuencia cardíaca máxima (FCmax) y pulso de oxígeno (VO_2/FC). Se calculó la diferencia porcentual entre ACE y LCE (relación AE/LE) para cada variable. Los datos se analizaron usando la prueba U de Mann-Whitney y se estableció una significación en $p < 0.05$.
Resultados: En comparación con las CS, las wwEM presentaron valores inferiores de VO_2pico ($p = 0.004$ y $p = 0.005$), Wpico ($p = 0.002$ y $p < 0.001$), FCmax ($p = 0.013$ y $p = 0.003$) y VEpico ($p = 0.003$ y $p = 0.001$) durante las evaluaciones con ACE y LCE, respectivamente. Las wwEM también mostraron un pulso de oxígeno menor que las CS ($p = 0.005$) durante la ACE, pero no durante la LCE. La relación ACE/LCE mostró que la potencia mecánica fue significativamente menor en las wwEM que las CS ($p = 0.045$).
Conclusiones: Las mujeres con leve a moderada esclerosis múltiple presentan una menor capacidad cardiovascular, pulmonar y muscular, así como una menor diferencia porcentual en la potencia de los brazos respecto a la potencia de las piernas, sugiriendo una mayor afectación de las extremidades inferiores en esta población.

Palabras clave

Pruebas de ejercicio; esclerosis múltiple; neurorrehabilitación; rendimiento físico; miembros superiores vs inferiores.

Introduction

Multiple Sclerosis (MS) is a chronic, degenerative disease of the central nervous system and represents the leading non-traumatic cause of disability among young adults. Patients with MS (pwMS) may present with a wide spectrum of symptoms including physichological and emotional problems, sensory deficits, muscle weakness, impaired motor coordination and balance, and fatigue (Arévalo Baeza & Pacheco Fuertes, 2022; Royer et al., 2024; Valadkevičienė et al., 2024). These symptoms can affect functional capacity, quality of life, and the ability to perform activities of daily living to a greater or lesser extent (Chaves et al., 2024). Together with self-perceived barriers to physical activity, such symptoms result in pwMS exhibiting markedly lower levels of physical activity than age-matched individuals from the general population, often falling well below the thresholds recommended for maintaining health (Gomes et al., 2024; Sieber et al., 2024; van der Ven et al., 2024).

The study of the muscular repercussions of the disease is commonly conducted by assessing different manifestations of isometric (Uygur et al., 2022), isokinetic (Ramari et al., 2020; Farrell et al., 2021), or dynamic strength (Portilla-Cueto, et al., 2022a; Portilla-Cueto, et al., 2022b), with or without electromyographic recording (Beretta-Piccoli et al., 2020). However, in pwMS, assessment of leg ergospirometric capacity are less common, and arm-crank ergospirometry is performed even more rarely (Langeskov-Christensen et al., 2015; Canning & Hicks, 2020). It has been consistently reported that pwMS exhibit a reduction in maximal oxygen uptake (VO_2max) compared with healthy individuals, a reduction that is inversely associated with the degree of neurological disability (Rasova et al., 2005; Koseoglu et al., 2006; Heine et al., 2014; Albergoni et al., 2025).

In a clinical context, ergospirometric testing enables the assessment of aerobic capacity limits and the integrated function of the pulmonary, cardiovascular, and muscular systems (Dores et al., 2024; Tauda & Cruzat Bravo, 2025). VO_2max can be constrained by several central (or supply-realated) factors, such as ventilation, alveolar-capillary diffusion, oxygen transport capacity in the blood, cardiac output, and tissue perfusion, which collectively determine the amount of oxygen delivered to the active muscles, or by peripheral muscular factors, including the muscles' capacity for oxygen diffusion and utilisation (Dores et al., 2024).

PwMS may also have reduced ventilatory capacity due to impairment of the respiratory muscles, particularly of the diaphragm (Koseoglu et al., 2006; Bosnak-Guclu et al., 2012; Tzelepis & McCool, 2015). Indeed, some studies have shown an inverse relationship between the degree of neurological disability and the extent of limitation in certain cycle ergospirometric variables (Rasova et al., 2005; Koseoglu et al., 2006; Heine et al., 2014; Albergoni et al., 2025).

Most studies assessing peak oxygen consumption (VO_2peak) in pwMS have used leg-cycle ergospirometry (LCE) (Langeskov-Christensen et al., 2015; Van Den Akker et al., 2015; Andreu-Caravaca et al., 2021). In contrast, relatively few studies have assessed VO_2peak using treadmill testing (Feasel et al., 2021; Apollonatou et al., 2023) or arm-crank ergospirometry (ACE) (Langeskov-Christensen et al., 2015; Canning & Hicks, 2020).

An aspect that remains insufficiently explored in the scientific literature is the comparison of the responses of ergospirometric variables during arm-crank ergometry (ACE) versus leg-cycle ergometry (LCE) in pwMS (Langeskov-Christensen et al., 2015; Andreu-Caravaca et al., 2021; Youssef et al., 2024). Studies analysing the percentage difference in ergospirometric variables between ACE and LCE (ACE/LCE ratio) in healthy populations have shown that arm performance is lower than leg performance, and that this ratio decreases with advancing age (Tordi et al., 2001; Pogliaghi et al., 2006; Price et al., 2024). The ACE/LCE ratio of ergospirometric variables may therefore provide valuable insights into the extent to which central or peripheral factors limit aerobic capacity in pwMS compared with healthy individuals.

In general, it is accepted that lower limb involvement is more pronounced than upper limb involvement in pwMS (Kister et al., 2013; Ramari et al., 2020; Ozkul et al., 2022). Therefore, in this pilot study, we hypothesised that pwMS would desmonstrate lower performance in LCE than in ACE when compared with healthy controls. To further explore this difference, the ACE/LCE ratio was also compared between groups, which may provide a valuable foundation for future research in the field of neurorehabilitation.

Method

Study design

This pilot study employed a descriptive cross-sectional design. Two ergospirometric assessments were conducted in a randomised order, separated by at least 48 hours: one using only the upper limbs (ACE) and the other using only the lower limbs (LCE).

Participants

Twenty women participated in the study: including ten women with relapsing-remitting MS (wwMS) and ten healthy controls (HC), matched for age, body weight, and body mass index (BMI). A convenience sampling approach was used. Participants were recruited and contacted through the Multiple Sclerosis Association of León. Prior to the exercise tests, all participants underwent a clinical-medical history assessment to evaluate their overall health status and the degree of neurological disability, under the supervision of a physician.

The inclusion criteria for patients were as follows: a confirmed diagnosis of MS according to the McDonald criteria (McDonald et al., 2001); maintenance of ambulatory autonomy (with or without assistance) for at least 20 metres without rest; no episodes of relapse or evident functional deterioration in the preceding two months; and a degree of neurological disability, assessed using the Expanded Disability Status Scale (EDSS), below 5. In addition, participants were required not to have engaged in structured physical activity during the previous six months and to be free of metabolic, cardiovascular, pulmonary, or musculoskeletal conditions that could contraindicate maximal exertion.

Ethical Approval

The study was approved by the Research Ethics Committee of the University of León, Spain (30 January 2017, study number: 1835) and conducted in accordance with international standards and the Declaration of Helsinki. Before participation, all subjects were fully informed of the study's purpose and provided written informed consent.

Procedure

The ergospirometric assessments were carried out in the Exercise Physiology Laboratory of the Institute of Biomedicine (IBIOMED) at the University of León, using two ergometers: the Monark Rehab-Trainer (model 881E, UK) for ACE and an Ergoline ergometer (model 900, Bitz, Germany) for LCE. For both tests, the ergometer protocol consisted of a continuous progressive ramp with a cadence of 60 rpm and an initial workload of 20 W for LCE and 10 W for ACE, with increments every minute of 20 W (Romberg et al., 2004) and 10 W (Pilutti et al., 2015), respectively, until volitional exhaustion or the inability to maintain a cadence above 55 rpm. Breath-by-breath gas exchange was continuously analysed (Ergocard, Medisoft, Dinant, Belgium), and a 12-lead ECG was monitored throughout both tests.

Variables analysed

The ergospirometric variables analysed were: peak oxygen consumption (VO_2peak), peak mechanical power (Wpeak), respiratory quotient (RQ = VCO_2/VO_2), peak pulmonary ventilation (VEpeak), maximal heart rate (HRmax), and oxygen pulse (VO_2/HR) at the point of exercise termination. These variables were compared between wwMS and HC for both ACE and LCE, as well as for the percentage difference between ACE and LCE for each variable.

Data analysis

Data are presented as mean ± standard deviation (SD). The normality of the data distribution was assessed using the Shapiro-Wilk test. Comparisons of quantitative variables between wwMS and HC were performed using the Mann-Whitney U test. The percentage difference between ACE and LCE (ACE/LCE ratio) was calculated using the equation: ACE/LCE ratio = [(ACE × 100) / LCE]. Results are expressed as percentages (%), with values closer to 100 indicating a smaller percentage difference (e.g., ergospirometric values obtained during ACE were closer to those obtained during LCE), whereas values further from 100 indicate a larger difference. Effect size was calculated using Rosenthal's *r*. Statistical significance was set at $p < 0.05$. All analyses were performed using SPSS version 25.0 (SPSS Inc., Chicago, IL, USA).

Results

The general characteristics of women with MS and healthy controls are presented in Table 1. No significant differences were found in age, body weight, height, or BMI. Table 1 also includes the EDSS score (range, 2-5) and the time elapsed since diagnosis.

Table 1. Characteristics of women with MS (n =10) and healthy controls (n =10)

Characteristics	WwMS			Controls			*p*
	Mean	±	SD	Mean	±	SD	
Age (years)	45.6	±	13.1	44.0	±	11.1	0.684
Weight (kg)	60.5	±	4.6	61.7	±	11.0	0.796
Height (cm)	157.1	±	6.0	159.0	±	6.3	0.912
BMI (kg/m^2)	24.2	±	2.3	24.3	±	3.0	0.971
EDSS (range, 0-10)	2.9	±	1.4	-		-	-
Diagnosis EDSS (years)	9.0	±	3.9	-		-	-

SD: standard deviation; wwMS: women with multiple sclerosis; EDSS: Expanded Disability Status Scale; BMI: body mass index; *p*: p value.

Table 2 presents the ergospirometric variables for both LCE and ACE in wwMS and HC. WwMS showed lower values than HC in Wpeak, VO_2peak, HRmax, and VEpeak for both LCE and ACE. In contrast, VO_2/HR was significantly lower in wwMS compared with HC only during ACE, but not during LCE. No significant differences between groups were observed for RQ.

Table 2. Ergospirometric responses during leg-cycle and arm-crank ergometry in women with MS and healthy controls

	Leg-cycle ergometry									Arm-crank ergometry								
	WwMS			Controls			*Z*	*p*	*ES*	WwMS			Controls			*Z*	*p*	*ES*
Variable	Mean	±	SD	Mean	±	SD				Mean	±	SD	Mean	±	SD			
Wpeak	85.8	±	26.1	141.0	±	13.7	-3.48	0.000	0.78	37.2	±	7.1	50.0	±	6.7	-3.13	0.002	0.70
VO_2peak	22.4	±	5.4	30.5	±	4.8	-2.80	0.005	0.63	16.0	±	3.1	23.4	±	5.1	-2.87	0.004	0.64
HRmax	140.4	±	13.1	166.9	±	17.0	-2.99	0.003	0.67	127.5	±	13.6	151.2	±	20.8	-2.50	0.013	0.56
VO_2/HR	9.5	±	1.9	11.2	±	2.3	-1.74	0.082	0.39	7.5	±	1.4	9.4	±	1.6	-2.80	0.005	0.63
RQ	1.15	±	0.1	1.23	±	0.2	-1.23	0.218	0.28	1.11	±	0.1	1.19	±	0.1	-1.60	0.110	0.36
VEpeak	45.6	±	7.2	67.7	±	14.0	-3.25	0.001	0.73	37.0	±	8.2	49.1	±	7.3	-2.95	0.003	0.66

SD: standard deviation; wwMS: women with multiple sclerosis; Wpeak: peak mechanical power in watts (W); VO_2peak: peak oxygen consumption (ml/kg/min); RQ: respiratory quotient (VCO_2/VO_2); VEpeak: peak pulmonary ventilation (L/min); HRmax: maximal heart rate; VO_2/HR: oxygen pulse; *Z*: Z statistic from the Mann-Whitney U test; *p*: p-value; *ES*: effect size.

Table 3 presents the results of the ACE/LCE ratio. Notably, only the mean Wpeak in wwMS was significantly lower than in HC, with no other variables showing significant differences between the groups.

Table 3. Percentage ratio between arm-crank and leg-cycle ergometry in women with MS and healthy controls

	ACE/LCE ratio (%)								
	WwMS			Controls			*Z*	*p*	*ES*
Variable	Mean	±	SD	Mean	±	SD			
Wpeak	46.4	±	13.1	35.8	±	6.2	-2.00	0.045	0.45
VO_2peak	73.6	±	12.7	76.5	±	9.7	-0.23	0.821	0.05
HRmax	90.9	±	5.7	90.4	±	5.6	-0.11	0.910	0.03
VO_2/HR	80.6	±	13.4	84.7	±	9.2	-0.23	0.821	0.05
RQ	99.2	±	3.4	97.5	±	11.5	-0.30	0.762	0.07
VEpeak	81.4	±	13.8	74.6	±	14.2	-1.21	0.226	0.27

SD: standard deviation; wwMS: women with multiple sclerosis; Wpeak: peak mechanical power in watts (W); VO_2peak: peak oxygen consumption (ml/kg/min); RQ: respiratory quotient (VCO_2/VO_2); VEpeak: peak pulmonary ventilation (L/min); HRmax: maximal heart rate; VO_2/HR: oxygen pulse; *Z*: Z statistic from the Mann-Whitney U test; *p*: p-value; *ES*: effect size; ACE: arm-crank ergometry; LCE: leg-cycle ergometry; ACE/LCE ratio: percentage difference between ACE and LCE; %: variable values expressed as percentages.

Discussion

The present study demonstrates that young women with MS with mild to moderate neurological disability (as measured by the EDSS) exhibit lower peak mechanical power, peak oxygen consumption, maximal heart rate, and peak pulmonary ventilation during both leg-cycle and arm-crank ergometry compared with healthy controls. Furthermore, the percentage differences between the ergospirometric variables obtained during arm-crank ergometry relative to those obtained during leg-cycle ergometry are generally similar, except for the percentage difference in mechanical power between arms and legs, which is lower in women with MS. This suggests that, in this population, the lower limbs are more affected than the upper limbs.

Studies evaluating the functional capacity of pwMS are usually conducted in mixed-sex samples, in which, at best, there is a similar proportion of men and women; however, these samples do not reflect the sex-specific incidence of this disease, and therefore, the conclusions may be biased (Apollonatou et al., 2023; Schlagheck et al., 2023; Hibner et al., 2024; Albergoni et al., 2025). The present study focuses specifically on young adult women with MS, with healthy controls matched for age and BMI. As MS typically manifests in young adults (McGinley et al., 2021), it is not surprising that, despite our sample being young, the average disease duration is 9.0 ± 3.9 years. Given that MS tends to progress in severity over time, it is crucial that, when comparing different studies in pwMS, both the degree of neurological disability and disease duration of the participants are taken into account, as the prevalence of clinical manifestations changes over the years following diagnosis (Kister et al., 2013).

In ergometry performed using continuous progressive protocols, peak mechanical power is closely correlated with both total test duration and VO_2peak (Dores et al., 2024). WwMS exhibit lower peak leg-cycle ergometer power, with reductions of approximately 39% in power output and 27% in VO_2peak compared with healthy controls. These findings are consistent with previous studies reporting lower muscle power and reduced peak oxygen consumption during leg-cycle ergometry in people with MS compared with healthy populations (Langeskov-Christensen et al., 2015; Klaren et al., 2016; van der Ven et al., 2024).

Women with MS have low aerobic fitness (low VO_2peak) during both arm- and leg-based exercise. The reduced VO_2peak levels observed are likely attributable to the interaction of multiple factors, including sedentary behaviour (Motl & Baird, 2021), low cardiovascular fitness (low HRmax), alterations in muscle oxidative capacity (Spaas et al., 2022), and disease-related manifestations such as neurological disability and prolonged disease duration (Romberg et al., 2004; Rasova et al., 2005; Koseoglu et al., 2006; Albergoni et al., 2025). Nevertheless, the ACE/LCE ratio for VO_2peak does not differ between wwMS (73.6%) and HC (76.5%); values comparable to the mean reported for the general population (~70%) (Price et al., 2024). These findings suggest that, although women with MS have lower aerobic capacity during both leg and arm exercise, the proportional difference in oxygen consumption between these exercise modes remains similar to that of healthy women. Therefore, interventions should aim to enhance aerobic fitness and mitigate conventional cardiovascular and cerebrovascular risk factors in this population (Lin et al., 2024; Albergoni et al., 2025).

Individuals with MS are characterised by a progressive decline in functional mobility (Chaves et al., 2024), commonly associated with lower-limb muscle weakness that worsens as the disease progresses (Kister et al., 2013; Ramari et al., 2020). In line with this, women with MS in our cohort show a lower ACE/LCE ratio for Wpeak compared with healthy controls (46.4% vs. 35.8%, $p = 0.045$), indicating that arm power corresponds to 46.4% of leg power in women with MS, whereas in healthy controls it is 35.8%. This result highlights reduced lower limb ergometric performance in women with MS, reflecting peripheral muscle weakness. Given the crucial role of the lower limbs in functional activities such as walking, standing up, and maintaining postural stability (Grazioli et al., 2019; Taul-Madsen et al., 2021), these findings support prioritising targeted lower-limb strength and power training in rehabilitation strategies for women with MS. Overall, these data underscore the importance of addressing lower-limb muscle performance to mitigate mobility limitations and improve functional independence in MS (Medina-Perez et al., 2014, 2016; Patrocinio de Oliveira et al., 2018).

With regard to HRmax, women with MS present a generalised reduction in both ergometric tests, with similar decreases in the legs (~15.9%) and arms (~15.7%) compared with healthy controls. This finding corroborates previous reports on people with MS (Rasova et al., 2005; Heine et al., 2014; Klaren et al.,

2016). The lower cardiovascular performance observed in wwMS may be attributed to cardiac autonomic dysfunction, a recognised feature of the disease (Kaplan et al., 2015; Findling et al., 2020). None of the participants were receiving beta-blocker therapy; therefore, the reduced HRmax values cannot be attributed to medication. Furthermore, the ACE/LCE ratio for HRmax is similar between groups, suggesting that, despite the overall reduction in cardiovascular performance in both legs and arms, the relative difference in cardiovascular response between the two exercise modes remains proportional in women with MS and healthy women. Overall, these findings highlight the importance of considering limb-specific cardiovascular limitations when designing aerobic training interventions for women with mild to moderate MS.

Oxygen pulse represents the product of stroke volume and oxygen extraction during each cardiac contraction (Peterman et al., 2021). During LCE, no differences is observed between groups, consistent with previous findings in individuals with mild MS (Tantucci et al., 1996; Hibner et al., 2024). However, during ACE, wwMS show a lower oxygen pulse (~20.2%) than HC, indicating a reduction in stroke volume per beat. This decrease likely reflects the combined effects of lower cardiovascular capacity (low HRmax) and reduced aerobic capacity (lower VO_2peak) in wwMS, which may limit oxygen delivery per beat during arm exercise. Nevertheless, the ACE/LCE ratio for oxygen pulse is similar between groups, suggesting that, although the mean oxygen pulse during arm exercise is lower in women with MS, the proportional difference between arm and leg exercise remains comparable to healthy controls.

Mean RQ values are similar between wwMS and HC in both the lower and upper limbs. These findings align with previous reports in individuals with mild MS (Heine et al., 2014; Klaren et al., 2016) and confirm that women with mild to moderate MS can achieve values indicative of maximal effort, with an RQ ≥ 1.10 considered a criterion for metabolic stress (Schlagheck et al., 2023). Moreover, the ACE/LCE ratio for RQ remains stable between groups, suggesting that the proportional difference in metabolic stress between arms and legs is preserved in wwMS, comparable to HC.

Women with MS also show lower minute ventilation during both exercise modalities compared with healthy controls. These results confirm previous reports describing reduced ventilatory capacity in this population (Koseoglu et al., 2006; Klaren et al., 2016). Nevertheless, the ACE/LCE ratio for VEpeak does not differ significantly between groups, suggesting that, although wwMS have lower ventilatory capacity than HC, the relative ventilatory response between leg and arm exercise remains proportional in both groups. The observed reduction in ventilatory capacity in women with MS is likely attributable to respiratory muscle weakness and the lower workloads achieved in both limbs (lower Wpeak). Collectively, these factors likely limit further hyperventilation when CO_2 production increases as a result of muscular metabolic stress at high intensities, which may substantially restrict airflow between the atmosphere and the lungs in this population.

This study provides valuable information to neurorehabilitation and healthcare professionals regarding the ergospirometric responses of the lower and upper limbs in people with MS. However, as a pilot study, it has several limitations that should be considered. Its cross-sectional design precludes the establishment of cause-and-effect relationships. The sample size is small and restricted to women with relapsing-remitting MS (RRMS) and mild to moderate disability (EDSS ≤ 5), which limits the generalisability of the findings to men and to patients with more advanced disability (EDSS > 5). In addition, given the small sample size, the impossibility of ruling out the existence of a Type I error is noted. Moreover, physical activity levels are not assessed, preventing characterisation of participants' lifestyle patterns. Future research should aim to include a larger sample encompassing participants of both sexes and varying levels of disability.

Conclusions

Women with mild to moderate MS exhibit lower cardiovascular, pulmonary, and muscular capacity compared with healthy women in both leg- and arm-ergospirometric assessments. Moreover, this study confirms that women with MS present a peripheral muscle-origin limitation, characterised by more pronounced weakness in the lower-limb muscles.

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References

Albergoni, M., Preziosa, P., Meani, A., Dallari, C., Valsasina, P., Rocca, M. A., & Filippi, M. (2025). Aerobic capacity moderates the association between cervical cord atrophy and clinical disability in mildly disabled multiple sclerosis patients. *Multiple Sclerosis*, *31*(5), 558–567. https://doi.org/10.1177/13524585251318647

Andreu-Caravaca, L., Ramos-Campo, D. J., Chung, L. H., & Rubio-Arias, J. (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

Apollonatou, V., Lykouras, D., Kargiotis, O., Kasdagli, M. I., Lagiou, O., Papathanasopoulos, P., Spiropoulos, K., & Karkoulias, K. (2023). Cardiopulmonary exercise testing in people with minimally impaired multiple sclerosis. *Multiple Sclerosis and Related Disorders*, *79*, 105016. https://doi.org/10.1016/j.msard.2023.105016

Arévalo Baeza, M., & Pacheco Fuertes, A. (2022). Expresión corporal, danza y esclerosis múltiple: beneficios emocionales en una intervención durante la contingencia de la COVID-19 (Body language, dance and multiple sclerosis: emotional benefits in an intervention during the COVID-19 contingency). *Retos*, *45*, 34–42. https://doi.org/10.47197/retos.v45i0.91470

Beretta-Piccoli, M., Cescon, C., Barbero, M., Villiger, M., Clijsen, R., Kool, J., Kesselring, J., & Bansi, J. (2020). Upper and lower limb performance fatigability in people with multiple sclerosis investigated through surface electromyography: A pilot study. *Physiological Measurement*, *41*(2), 025002. https://doi.org/10.1088/1361-6579/ab6f54

Bosnak-Guclu, M., Guclu-Gunduz, A., Nazliel, B., & Irkec, C. (2012). Comparison of functional exercise capacity, pulmonary function and respirator y muscle strength in patients with multiple sclerosis with different disability levels and healthy controls. *Journal of Rehabilitation Medicine*, *44*(1), 80–86. https://doi.org/10.2340/16501977-0900

Canning, K. L., & Hicks, A. L. (2020). Benefits of adhering to the canadian physical activity guidelines for adults with multiple sclerosis beyond aerobic fitness and strength. *International Journal of MS Care*, *22*(1), 15–21. https://doi.org/10.7224/1537-2073.2018-061

Chaves, A. R., Edwards, T., Awadia, Z., Morin, V., Walker, L. A. S., Reed, J. L., & Pilutti, L. A. (2024). Physiological fitness in people with advanced multiple sclerosis. *Multiple Sclerosis and Related Disorders*, *91*, 105854. https://doi.org/10.1016/j.msard.2024.105854

Dores, H., Mendes, M., Abreu, A., Durazzo, A., Rodrigues, C., Vilela, E., Cunha, G., Gomes Pereira, J., Bento, L., Moreno, L., Dinis, P., Amorim, S., Clemente, S., & Santos, M. (2024). Cardiopulmonary exercise testing in clinical practice: Principles, applications, and basic interpretation. *Revista Portuguesa de Cardiologia*, *43*(9), 525–536. https://doi.org/10.1016/j.repc.2024.01.005

Farrell, J. W., Motl, R. W., Learmonth, Y. C., & Pilutti, L. A. (2021). Persons with Multiple Sclerosis Exhibit Strength Asymmetries in both Upper and Lower Extremities. *Physiotherapy, Lond.*, *111*, 83–91. https://doi.org/10.1016/j.physio.2020.07.006

Feasel, C. D., Sandroff, B. M., & Motl, R. W. (2021). Aerobic reserve capacity in multiple sclerosis—Preliminary evidence. *Acta Neurologica Scandinavica*, *144*(3), 260–265. https://doi.org/10.1111/ane.13441

Findling, O., Hauer, L., Pezawas, T., Rommer, P. S., Struhal, W., & Sellner, J. (2020). Cardiac autonomic dysfunction in multiple sclerosis: A systematic review of current knowledge and impact of immunotherapies. *Journal of Clinical Medicine*, *9*(2), 335. https://doi.org/10.3390/jcm9020335

Gomes, L. R., Damasceno, B. P., de Campos, B. M., & Damasceno, A. (2024). Impairment of daily occupations in multiple sclerosis: analysis of neuroimaging, general and social cognition, and reserve. *Multiple Sclerosis and Related Disorders*, *81*, 105140. https://doi.org/10.1016/j.msard.2023.105140

Grazioli, E., Tranchita, E., Borriello, G., Cerulli, C., Minganti, C., & Parisi, A. (2019). The Effects of Concurrent Resistance and Aerobic Exercise Training on Functional Status in Patients with Multiple Sclerosis. *Current Sports Medicine Reports*, *18*(12), 452–457. https://doi.org/10.1249/JSR.0000000000000661

Heine, M., Hoogervorst, E. L. J., Hacking, H. G. A., Verschuren, O., & Kwakkel, G. (2014). Validity of maximal exercise testing in people with multiple sclerosis and low to moderate levels of disability. *Physical Therapy*, *94*(8), 1168–1175. https://doi.org/10.2522/ptj.20130418

Hibner, B. A., Lima, N. S., Sherman, S. R., Motl, R. W., Chirinos, J. A., Phillips, S., Clifford, P. S., Reder, A. T., Baynard, T., & Fernhall, B. (2024). Cardiovascular hemodynamic response to peak exercise in individuals with multiple sclerosis. *Physiological Reports*, *12*(24), e70150. https://doi.org/10.14814/phy2.70150

Kaplan, T. B., Berkowitz, A. L., & Samuels, M. A. (2015). Cardiovascular Dysfunction in Multiple Sclerosis. *The Neurologist*, *20*(6), 108–114. https://doi.org/10.1097/NRL.0000000000000064

Kister, I., Bacon, T. E., Chamot, E., Salter, A. R., Cutter, G. R., Kalina, J. T., & Herbert, J. (2013). Natural history of multiple sclerosis symptoms. *International Journal of MS Care*, *15*(3), 146–158. https://doi.org/10.7224/1537-2073.2012-053

Klaren, R. E., Sandroff, B. M., Fernhall, B., & Motl, R. W. (2016). Comprehensive Profile of Cardiopulmonary Exercise Testing in Ambulatory Persons with Multiple Sclerosis. *Sports Medicine*, *46*(9), 1365–1379. https://doi.org/10.1007/s40279-016-0472-6

Koseoglu, B. F., Gokkaya, N. K. O., Ergun, U., Inan, L., & Yesiltepe, E. (2006). Cardiopulmonary and metabolic functions, aerobic capacity, fatigue and quality of life in patients with multiple sclerosis. *Acta Neurologica Scandinavica*, *114*(4), 261–267. https://doi.org/10.1111/j.1600-0404.2006.00598.x

Langeskov-Christensen, M., Heine, M., Kwakkel, G., & Dalgas, U. (2015). Aerobic Capacity in Persons with Multiple Sclerosis: A Systematic Review and Meta-Analysis. *Sports Medicine*, *45*(6), 905–923. https://doi.org/10.1007/s40279-015-0307-x

Lin, C.-C., Kinnett-Hopkins, D., Alawamleh, A., Siemen, M., Lane, A., & Abou, L. (2024). Physical activity improves cardiovascular fitness and reduces cardiovascular risk factors in adults with multiple sclerosis: A systematic review and meta-analysis. *Multiple Sclerosis and Related Disorders*, *92*, 106170. https://doi.org/10.1016/j.msard.2024.106170

McDonald, W. I., Compston, A., Edan, G., Goodkin, D., Hartung, H. P., Lublin, F. D., McFarland, H. F., Paty, D. W., Polman, C. H., Reingold, S. C., Sandberg-Wollheim, M., Sibley, W., Thompson, A., Van Den Noort, S., Weinshenker, B. Y., & Wolinsky, J. S. (2001). Recommended diagnostic criteria for multiple sclerosis: Guidelines from the International Panel on the Diagnosis of Multiple Sclerosis. *Annals of Neurology*, *50*(1), 121–127. https://doi.org/10.1002/ana.1032

McGinley, M. P., Goldschmidt, C. H., & Rae-Grant, A. D. (2021). Diagnosis and Treatment of Multiple Sclerosis: A Review. *JAMA*, *325*(8), 765–779. https://doi.org/10.1001/jama.2020.26858

Medina-Perez, C., De Souza-Teixeira, F., Fernandez-Gonzalo, R., & De Paz-Fernandez, J. A. (2014). Effects of a resistance training program and subsequent detraining on muscle strength and muscle power in multiple sclerosis patients. *NeuroRehabilitation*, *34*(3), 523–530. https://doi.org/10.3233/NRE-141062

Medina-Perez, C., de Souza-Teixeira, F., Fernandez-Gonzalo, R., Hernandez-Murua, J. A., & de Paz-Fernandez, J. A. (2016). Effects of high-speed power training on muscle strength and power in patients with multiple sclerosis. *Journal of Rehabilitation Research and Development*, *53*(3), 359–368. https://doi.org/10.1682/JRRD.2014.08.0186

Motl, R. W., & Baird, J. F. (2021). Cardiorespiratory fitness and moderate-to-vigorous physical activity in older adults with multiple sclerosis. *Multiple Sclerosis Journal - Experimental, Translational and Clinical*, *7*(4), 20552173211057514. https://doi.org/10.1177/20552173211057514

Ozkul, C., Eldemir, K., Eldemir, S., Yildirim, M. S., Saygili, F., Guclu-Gunduz, A., & Irkec, C. (2022). Functional Performance, Leg Muscle Strength, and Core Muscle Endurance in Multiple Sclerosis Patients With Mild Disability: A Cross-Sectional Study. *Motor Control*, *26*(4), 729–747. https://doi.org/10.1123/mc.2021-0129

Patrocinio de Oliveira, C. E., Moreira, O. C., Carrión-Yagual, Z. M., Medina-Pérez, C., & de Paz, J. A. (2018). Effects of Classic Progressive Resistance Training Versus Eccentric-Enhanced Resistance Training in People With Multiple Sclerosis. *Archives of Physical Medicine and Rehabilitation*, *99*(5), 819–825. https://doi.org/10.1016/j.apmr.2017.10.021

Peterman, J. E., Harber, M. P., Chaudhry, S., Arena, R., & Kaminsky, L. A. (2021). Peak oxygen pulse and mortality risk in healthy women and men: The Ball State Adult Fitness Longitudinal Lifestyle Study (BALL ST). *Progress in Cardiovascular Diseases*, *68*, 19–24. https://doi.org/10.1016/j.pcad.2021.07.001

Pilutti, L. A., Sandroff, B. M., Klaren, R. E., Learmonth, Y. C., Platta, M. E., Hubbard, E. A., Stratton, M., & Motl, R. W. (2015). Physical fitness assessment across the disability spectrum in persons with multiple sclerosis: A comparison of testing modalities. *Journal of Neurologic Physical Therapy*, *39*(4), 241–249. https://doi.org/10.1097/NPT.0000000000000099

Pogliaghi, S., Terziotti, P., Cevese, A., Balestreri, F., & Schena, F. (2006). Adaptations to endurance training in the healthy elderly: Arm cranking versus leg cycling. *European Journal of Applied Physiology*, *97*(6), 723–731. https://doi.org/10.1007/s00421-006-0229-2

Portilla-Cueto, K., Medina-Pérez, C., Romero-Pérez, E. M., Hernández-Murúa, J. A., Vila-Chã, C., & de Paz, J. A. (2022). Reliability of Isometric Muscle Strength Measurement and Its Accuracy Prediction of Maximal Dynamic Force in People with Multiple Sclerosis. *Medicina (Kaunas)*, *58*(7), 948. https://doi.org/10.3390/medicina58070948

Portilla-Cueto, K., Medina-Pérez, C., Romero-Pérez, E. M., Núñez-Othón, G., Horta-Gim, M. A., & de Paz, J. A. (2022). Muscle Quality of Knee Extensors Based on Several Types of Force in Multiple Sclerosis Patients with Varying Degrees of Disability. *Medicina (Kaunas)*, *58*(2), 316. https://doi.org/10.3390/medicina58020316

Price, M. J., Smith, P. M., Bottoms, L. M., & Hill, M. W. (2024). The effect of age and sex on peak oxygen uptake during upper and lower body exercise: A systematic review. *Experimental Gerontology*, *190*, 112427. https://doi.org/10.1016/j.exger.2024.112427

Ramari, C., Hvid, L. G., David, A. C. de, & Dalgas, U. (2020). The importance of lower-extremity muscle strength for lower-limb functional capacity in multiple sclerosis: Systematic review. *Annals of Physical and Rehabilitation Medicine*, *63*(2), 123–137. https://doi.org/10.1016/j.rehab.2019.11.005

Rasova, K., Brandejsky, P., Havrdova, E., Zalisova, M., & Rexova, P. (2005). Spiroergometric and spirometric parameters in patients with multiple sclerosis: Are there any links between these parameters and fatigue, depression, neurological impairment, disability, handicap and quality of life in multiple sclerosis? *Multiple Sclerosis*, *11*(2), 213–221. https://doi.org/10.1191/1352458505ms1155oa

Romberg, A., Virtanen, A., Aunola, S., Karppi, S. L., Karanko, H., & Ruutiainen, J. (2004). Exercise capacity, disability and leisure physical activity of subjects with multiple sclerosis. *Multiple Sclerosis*, *10*(2), 212–218. https://doi.org/10.1191/1352458504ms1001oa

Royer, N., Mira, J., Lepetit, N., Fayolle, E., Camdessanché, J.-P., & Millet, G. Y. (2024). Benefits of Individualized Training in Fatigued Patients with Multiple Sclerosis. *Medicine and Science in Sports and Exercise*, *56*(9), 1623–1633. https://doi.org/10.1249/MSS.0000000000003474

Schlagheck, M. L., Bansi, J., Wenzel, C., Kuzdas-Sallaberger, M., Kiesl, D., Gonzenbach, R., & Zimmer, P. (2023). Complexity and pitfalls in maximal exercise testing for persons with multiple sclerosis. *European Journal of Neurology*, *30*(9), 2726–2735. https://doi.org/10.1111/ene.15875

Sieber, C., Haag, C., Polhemus, A., Haile, S. R., Sylvester, R., Kool, J., Gonzenbach, R., & von Wyl, V. (2024). Exploring the Major Barriers to Physical Activity in Persons With Multiple Sclerosis: Observational Longitudinal Study. *JMIR Rehabilitation and Assistive Technologies*, *11*, e52733. https://doi.org/10.2196/52733

Spaas, J., Goulding, R. P., Keytsman, C., Fonteyn, L., van Horssen, J., Jaspers, R. T., Eijnde, B. O., & Wüst, R. C. I. (2022). Altered muscle oxidative phenotype impairs exercise tolerance but does not improve after exercise training in multiple sclerosis. *Journal of Cachexia, Sarcopenia and Muscle*, *13*(5), 2537–2550. https://doi.org/10.1002/jcsm.13050

Tantucci, C., Massucci, M., Piperno, R., Grassi, V., & Sorbini, C. A. (1996). Energy cost of exercise in multiple sclerosis patients with low degree of disability. *Multiple Sclerosis*, *2*(3), 161–167. https://doi.org/10.1177/135245859600200307

Tauda, M., & Cruzat Bravo, E. (2025). Efecto del entrenamiento de fuerza y resistencia en la rehabilitación en cáncer de mama: evidencia actual y prácticas clínicas: revisión sistematica. *Retos*, *68*, 742–764. https://doi.org/10.47197/retos.v68.109370

Taul-Madsen, L., Connolly, L., Dennett, R., Freeman, J., Dalgas, U., & Hvid, L. G. (2021). Is Aerobic or Resistance Training the Most Effective Exercise Modality for Improving Lower Extremity Physical Function and Perceived Fatigue in People With Multiple Sclerosis? A Systematic Review and Meta-analysis. *Archives of Physical Medicine and Rehabilitation*, *102*(10), 2032–2048. https://doi.org/10.1016/j.apmr.2021.03.026

Tordi, N., Belli, A., Mougin, F., Rouillon, J. D., & Gimenez, M. (2001). Specific and transfer effects induced by arm or leg training. *International Journal of Sports Medicine*, *22*(7). https://doi.org/10.1055/s-2001-17608

Tzelepis, G. E., & McCool, F. D. (2015). Respiratory dysfunction in multiple sclerosis. *Respiratory Medicine*, *109*(6), 671–679. https://doi.org/10.1016/j.rmed.2015.01.018

Uygur, M., Barone, D. A., Dankel, S. J., & DeStefano, N. (2022). Isometric tests to evaluate upper and lower extremity functioning in people with multiple sclerosis: reliability and validity. *Multiple Sclerosis and Related Disorders*, *63*, 103817. https://doi.org/10.1016/j.msard.2022.103817

Valadkevičienė, D., Jatužis, D., Žukauskaitė, I., Danylaitė Karrenbauer, V., & Bileviciute-Ljungar, I. (2024). Revision of the brief international classification of functioning, disability and health core set for multiple sclerosis: a study of the comprehensive icf core set for multiple sclerosis with participants referred for work ability assessment. *Journal of Rehabilitation Medicine*, *56*, jrm19671. https://doi.org/10.2340/jrm.v56.19671

Van Den Akker, L. E., Heine, M., Van Der Veldt, N., Dekker, J., De Groot, V., & Beckerman, H. (2015). Feasibility and Safety of Cardiopulmonary Exercise Testing in Multiple Sclerosis: A Systematic Review. *Archives of Physical Medicine and Rehabilitation*, *96*(11), 2055–2066. https://doi.org/10.1016/j.apmr.2015.04.021

van der Ven, E., Patra, S., Riemann-Lorenz, K., Kauschke, K., Freese-Schwarz, K., Welsch, G., Krause, N., Heesen, C., & Rosenkranz, S. C. (2024). Individualized activity recommendation based on a physical fitness assessment increases short- and long-term regular physical activity in people with multiple sclerosis in a retrospective cohort study. *Frontiers in Neurology*, *15*, 1428712. https://doi.org/10.3389/fneur.2024.1428712

Youssef, H., Gönül, M. N., Sobeeh, M. G., Akar, K., Feys, P., Cuypers, K., & Vural, A. (2024). Is High-Intensity Interval Training More Effective Than Moderate Continuous Training in Rehabilitation of Multiple Sclerosis: A Comprehensive Systematic Review and Meta-analysis. *Archives of Physical Medicine and Rehabilitation*, *105*(8), 1545–1558. https://doi.org/10.1016/j.apmr.2023.12.012

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