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REVIEW

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Rehabilitation on cerebellar ataxic patients with multiple sclerosis: A systematic review

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Abstract

Multiple Sclerosis (MS) is a chronic inflammatory, autoimmune disease of the Central Nervous System with a vast spectrum of clinical phenotypes. A major aspect of its clinical presentation is cerebellar ataxia where physiotherapy and treatment modalities play a significant role on its management. This systematic review aims to investigate the physiotherapeutic rehabilitation techniques regarding the management of cerebellar ataxia due to MS and secondary to stratify each protocol as part of a multi structural personalized rehabilitation approach based on the gravity of the symptoms. A Pubmed Medline, Scopus and Web of Science research was performed using the corresponding databases. The results were screened by the authors in pairs. In our study, six (6) non-pharmacological interventional protocols, 3 Randomized Controlled Trials and 3 pilot studies, were included with a total of 145 MS patients. Physiotherapeutic techniques, such as NDT-Bobath, robotic and visual biofeedback re-education protocols and functional rehabilitation techniques were included. In most cases cerebellar ataxic symptoms were decreased post-treatment. The overall quality of the studies included was of moderate level (level B). Rehabilitation in cerebellar ataxia due to MS should be based on multicentric studies with the scope of adjusting different types of treatments and physiotherapeutic techniques based on the severity of the symptom.

KEYWORDS
cerebellar ataxia, multiple sclerosis, physiotherapy, rehabilitation

Abbreviations: 10MWT, 10 minute walk test; 2MWT, 2 minute walk test; ABC, activities-specific balance confidence scale; AFG, auditory feedback group; APSI, anterior–posterior stability index; ARAT, action research arm test; BBS, Berg balance scale; BBTW, balance-based-torso-weighting; BI, Barthel Index; BT, balance training; CA, cerebellar ataxia; CBS, composite balance score; CCW, counterclockwise; CerA, cerebellar ataxia; CFSS, cerebellar functional system score; CG, control group; COB, center of balance; COP, center of pressure; COPM, Canadian occupational performance measure; CST, core stabilization training; CW, clockwise; EDSS, expanded disability status scale; FAHN, Fahn-Tolosa-Marin tremor rating scale; F_p, pertubating force field; FRT, functional reach test; FSS, fatigue severity scale; GAS, goal attainment scaling; GI, study group I; GII, study group II; GS, gait speed; ICARS, International Coooperative Ataxia Rating Scale; JI, jerk index; LI, learning index; LS, lumbar stabilization; MD, manipulation duration; Mini-BESTest, Mini- Balance Evaluation System Test; ML, mediolateral; MLSI, mediolateral stability index; MMLD, mean and max lateral deviation; MS, multiple sclerosis; MSQOL-54, multiple sclerosis quality of life-54; NDT-Bobath, neurodevelopmental treatment; NHPT, nine hole peg test; NPL, normalized path length; PIADS, psychological impact of assistive device scale; PT, physiotherapy; RAGT, robot-assisted gait training; RCT, randomized controlled trial; RD, reaching duration; RMT, reaching tasks and manipulation protocol; RT, reaching tasks protocol; SA, stabilometric assessment; SARA, scale for the assessment and rating of Ataxia; SIBT, sensory integration balance training; s-indexes, smoothness indexes; SOT, sensory organization test; SVV, subjective visual vertical deviations; TADL, tremor in activity of daily life; TBP, targeted ballet program; TD, treatment duration; TSS, tremor severity scale; TT, task-oriented training; TUG, timed up and go, 1; VAS, visual analogue scale; wk/s, week/s.

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1 | INTRODUCTION

Multiple sclerosis (MS) is a chronic, inflammatory, autoimmune disease of the central nervous system, which is characterized by demyelinating plaques disseminated in time and space, leading to a vast spectrum of clinical phenotypes (Walton et al., 2020).

The clinical phenotype of MS is nowadays considered a continuum were several pathophysiologic pathways take place. Balance impairments caused by cerebellar, vestibular, or deep sensory functional impairment is encountered fairly often, and still remains a significant challenge. A major aspect of clinical presentation on MS is cerebellar ataxia (CerA) which is an increase in postural sway, when the patient's eyes are open, or a decrease in the patient's Center of Balance (COB) (Stevens et al., 2013).

Physiotherapy and rehabilitation modalities, which are commonly employed to control CerA, are balance-specific exercises involving somatosensory and motor strategy facilitations. Some of the exercise modalities on cerebellar ataxia due to MS, include balance and lower body plyometric exercises, combined with aerobic, endurance and resistance training as well as treadmill walking (Carpinella et al., 2012; Klatt et al., 2019; Vergaro et al., 2010). Nowadays, additional functional rehabilitation techniques, (yoga, salsa dance, water aerobics) have been included in CerA-MS management (Latimer-Cheung et al., 2013).

Recent studies have also explored the use of robotic applications in CerA management. Robotic rehabilitation training has been found to be effective in improving balance, coordination, and gait in MS patients with ataxia (Carpinella et al., 2012; Klatt et al., 2019; Vergaro et al., 2010).

The purpose of this systematic review is to investigate the physiotherapeutic rehabilitation techniques regarding the management of CerA due to MS and also an attempt to stratify each protocol as part of a multi structural personalized rehabilitation approach based on the gravity of the symptom.

Significance

One of the most common and at the same time disabling symptoms of Multiple Sclerosis (MS) is cerebellar ataxia. It is a major factor of both disease worsening due to a clinical relapse (Relapse Associated Worsening-RAW) and disability progression independent of relapse activity (PIRA). The purpose of this systematic review is to investigate the different physiotherapeutic rehabilitation techniques that could be used in managing cerebellar ataxia and to classify each protocol according to its effect on such a debilitating symptom.

2 | METHODS AND MATERIALS

A systematic review of the literature was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). To identify relevant studies a PubMed Medline, Scopus and Web of Science research was performed using the corresponding databases. The search was limited to pilot studies and randomized controlled trials (RCTs) published between January 01, 2013 and January 01, 2023, which included the following keywords: rehabilitation, ataxia, and multiple sclerosis. The PICO criteria used are as follows. P: patients with clinical definite MS diagnosis, I: Interventions aimed to improve balance and co-ordination, C: patients with MS undergoing a single ataxia rehabilitation protocol, O: ICAS scale and kinematic analysis.

Three authors (AC, KS, DK) independently conducted the literature search and assessed the results before synthesizing the data. Studies that reported on rehabilitation of CerA due to MS patients were included while ataxia of different pathophysiology was excluded. In addition, studies were the keyword ataxia was replaced by terminology like incoordination, tremor, balance dysfunction, upper limb coordination dysfunction were also excluded.

Data were extracted from each included study using a standardized form. The data extracted included study design, sample size, rehabilitation techniques used, outcomes measured and study limitations. Any discrepancies in data extraction were resolved by consensus by the corresponding author (SG). The quality of the studies included in the review was assessed using the criteria proposed by Moore and Wolfson (Fga & Human, 2002) and the Canadian Task Force on the Periodic Health Examination (1979). A systematic synthesis of the included studies was performed due to the heterogeneity of the interventions and outcome measures. The results of the study are presented in Table 1 (Supplementary material).

3 | RESULTS

There were a total 6 non-pharmacological interventional studies regarding the rehabilitation of CerA in MS patients (Ali et al., 2020; Keser et al., 2013; Klatt et al., 2019; Rahimibarghani et al., 2022; Salcı et al., 2017; Scheidler et al., 2018). Of those 3 were RCTs and the interventions included two task-oriented training (TT) protocols (physiotherapy exercises based on mundane kinematic individual actions in order to perform those more efficiently) (Ali et al., 2020; Salcı et al., 2017) and a functional rehabilitation training approach (Scheidler et al., 2018). The remaining 3 were pilot studies, with a sample size range between 10 and 20 participants and included a combination of NDT-Bobath and conventional physiotherapy protocol (Keser et al., 2013), a robotic and visual biofeedback reeducation protocol (Klatt et al., 2019) and a functional rehabilitation technique (Rahimibarghani et al., 2022) (Table 1). A total of 145 MS patients were included in all 6 studies. Regarding the quality of the studies 4 out of 6 were rated as B and 2 out of 6 were rated as A which indicates an overall moderate quality rating of the data (Tables 2 and 3).

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TABLE 1 Descriptive table of studies

Author	Type of study	N	Intervention and measurements	Outcome measurements	Limitations	Study rating
Rahimibarghani et al. (2022)	Pilot	10 SPMS (EDSS 3.5–5.5) Minimum sample size: achieved	Cycling on stationary bike 12 sessions/ 6 weeks	↑COP related parameters ($p < .001$)	Patient selection based on EDSS score rather than cerebellar FS score. No follow-up	B
Ali et al. (2020)	RCT	45 RRMS (EDSS 2.0–4.5)	3 groups: 50 min-CST 50 min-TT 50 min-CBEP 2 sessions/ 6 weeks APSI MLSI	↑APSI and MLSI parameters for the TT group ($p < .05$)	Sample did not include progressive MS patients with irreversible ataxic symptoms.	A
Klatt et al. (2019)	Pilot	20 MS patients Minimum sample size: achieved	SVV with & rod-and-frame conditions. CW, CCW rotation BI BBS ICARS 10MWT SARA TUG	Significant correlation (CCW) BI ($p = .018$), BBS($p = .003$), ICARS ($p = .006$), SARA ($p = .002$), TUG ($p = .003$). Significant correlation (CW) BI (p = .001)	Heterogenous MS sample. No descriptive parameters No follow-up	B
Scheidler et al. (2018)	RCT	8 RRMS female patients (EDSS: 2.5–6.5)	2 TBP groups: 60 min/session, twice/week/ 16 weeks Minibuses ICARS GBM	42%↑Mini-Besets ($p < .001$, d = 1.2) 58% ↓ICARS: ($p = .001$, $d = 2.6$) Back Step GBM $p < .025$, ($d = 0.68$)	Significant EDSS variance, i.e. 6.5 is not considered moderate disability. Exclusion of patients not based on ataxia severity, but only on level of cognitive impairment.	B
Salcı et al. (2017)	RCT	42 MS patients EDSS:3.0–5.0)	3 groups: BT (45 min) LS + BT (90 min) TT + BT (90 min) 18 sessions BBS ICARS FRT 2MWT CBS	↑2MWT for the LS group ($p = .08$) ↓ICARS for the LS group ($p = .004$) and for the TT group ($p < .001$) ↑CBS for the LS group ($p = .002$) and for the TT group ($p = .027$)	Significant EDSS variance.	A

(Continues)

TABLE 1 (Continued)

Author	Type of study	N	Intervention and measurements	Outcome measurements	Limitations	Study rating
Keser et al. (2013)	Pilot	20 MS patients (EDSS: 0.5–2.5) Minimum sample size: achieved	Conventional PT or Bobath training 60 min/session, 3times/week, 8 weeks TIS ICARS BBS MSFC	Similar changes in both groups ($p > .05$)	Significant EDSS variance. MS sample heterogeneity No follow up	B

Abbreviations: 10MWT, 10 minute walk test; 2MWT, 2 minute walk test; APSI, anterior–posterior stability index; BBS, Berg balance scale; BI, Barthel index; BT, balance training; CBEP, conventional balance exercise physiotherapy; CBS, composite balance score; CCW, counterclockwise; COP, center of pressure; CST, core stabilization training; CW, clockwise; EDSS, expanded disability status scale; FRT, functional reach test; FS, functional systems; GBM, global balance measure; ICARS, international cooperative ataxia rating scale; LS, lumbar stabilization; Mini-BESTest, the mini-balance evaluation systems test; MLSI, mediolateral stability index; MS, multiple sclerosis; MSFC, multiple sclerosis functional composite; PPMS, primary progressing multiple sclerosis; RCT, randomized controlled trial; RRMS, Relapsing remitting multiple sclerosis; SARA, scale for the assessment and rating of Ataxia; SPMS, secondary progressive multiple sclerosis; SVV, subjective visual vertical; TBP, targeted ballet program; TIS, trunk impairment scale; TT, task-oriented training; TUG, timed up and go.

TABLE 2 Moore and Wolfson quality rating criteria

MS definition: Clear with reference to published criteria (2), Defined but not referred (1), Not defined (0)
MS population: Uniform (2), Heterogeneous (1), Not mentioned (0)
Recruitment strategy of controls: Defined from a priori study base (2), Defined (1), Absent (0)
Demographics: Provided for cases and controls (2), Different groups (1), Not mentioned (0)
Blinding: Yes (2), No (0)
Controls for technique: Positive and Negative controls (2), Methods described (1), No controls (0)
A: ≥8
B: 5–7
C:≤4

TABLE 3 Conclusions

Several rehabilitation techniques have been applied in the rehabilita ataxia due to MS
The majority of protocols have been studied in either RCTs or pilot-studies of moderate methodological quality
The nature of the protocols applied, is based on versatile rehabilitation principles and on the gravity of the ataxic symptoms.
A multi-disciplined approach seems to be the safest course of action regarding the efficacy of the applied rehabilitation protocol on ataxia

3.1 | Combination of conventional neurorehabilitation and NDT-Bobath methodology

A pilot study by Keser and colleagues conducted an outpatient protocol, of either NDT-Bobath based trunk exercises or routine neurorehabilitation program (Keser et al., 2013). The conclusions were non-significant, hence none of the two approaches was considered superior ($p > .05$). Based on the Moore and Wolfson criteria, the rating of this study was B.

3.2 | Robotic and visual biofeedback reeducation

Klatt and colleagues attempted to correlate, in a pilot study, subjective visual vertical (SVV) deviations and balance, with CerA in MS patients. Their results showed significant increase in Activities of Daily Living (ADL) ($p < .05$) and consequently, that adaptive robot training improved upper limb kinematics and functional ability in MS patients (Klatt et al., 2019). Based on the Moore and Wolfson criteria, the rating of this study was B (Figure 1).

3.3 | Task-oriented training

Salci and colleagues examined the effects of balance training (BT), lumbar stabilization (LS) and TT in 42 MS patients with CerA.

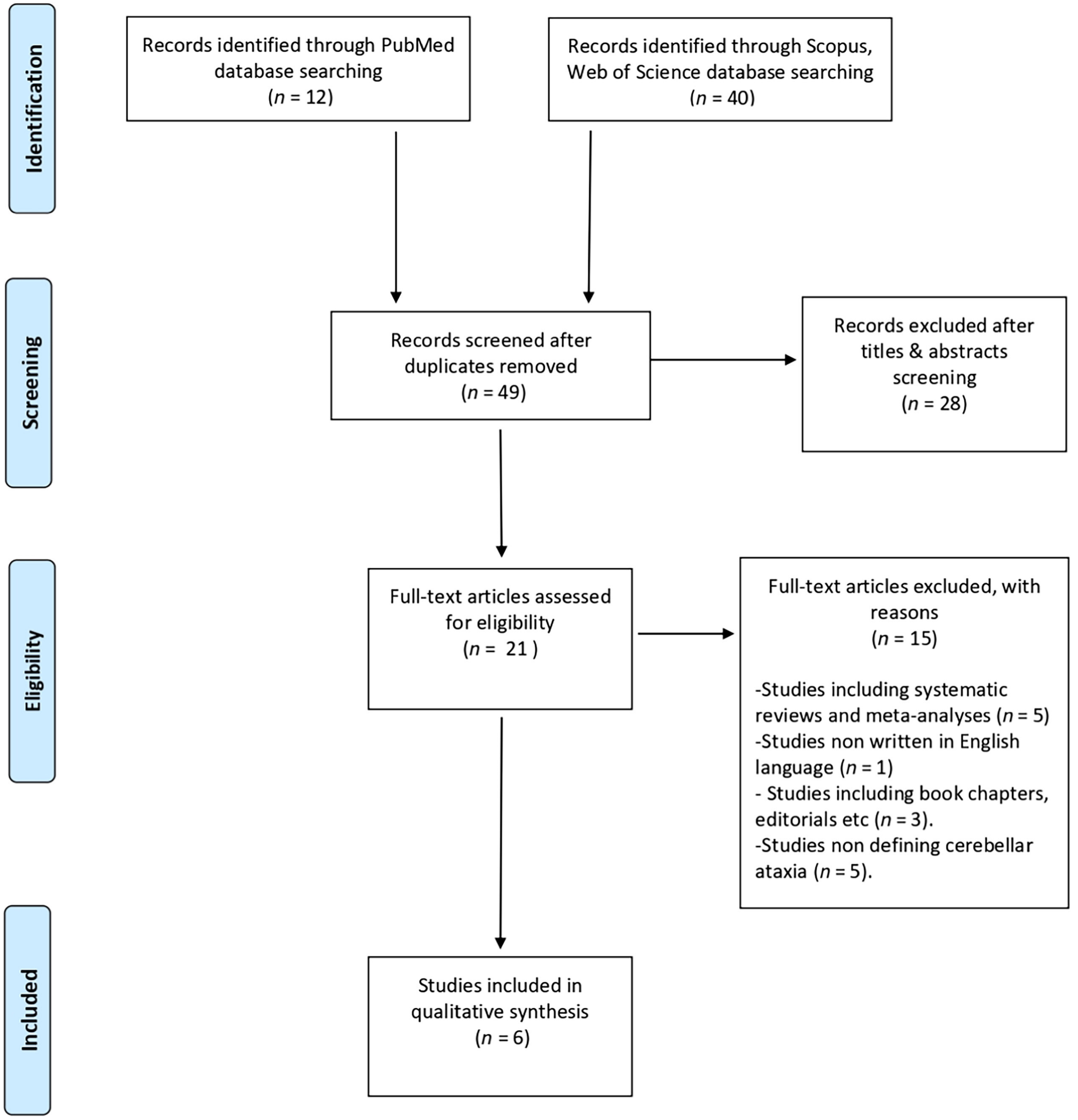

FIGURE 1 PRISMA flow chart.

Statistical analysis revealed significant improvement in kinetic function in both LS and TT groups ($p < 05$). As the result, the authors reported that CA rehabilitation should be multimodal with the inclusion of TT functional training programs in the core (Keser et al., 2013). Based on the Moore and Wolfson criteria, the rating of this study was A.

Ali and colleagues (Salcı et al., 2017) assessed TT program in 45 Relapse-Remit MS (RRMS) patients with CerA. The results indicated major improvement in functional scores regarding the TT group ($p < .005$) and concluded that an effective rehabilitation protocol regarding CerA should be based on TT ($p < .05$). Based on the Moore and Wolfson criteria, the rating of this study was A.

3.4 | Functional rehabilitation techniques

Scheidler and colleagues (Scheidler et al., 2018) examined a targeted ballet program (TBP) in order to mitigate CerA and improve balance in ataxic female patients with RRMS. Their findings demonstrated a significant improvement in static and dynamic gait patterns and in gait plasticity (p < .001). Based on the Moore and Wolfson criteria, the rating of this study was B.

Rahimibarghani and colleagues (Rahimibarghani et al., 2022) investigated, in a pilot study, the effects of cycling on gait parameters on 10 Secondary Progressive MS (SPMS) patients with CerA. Statistical analysis revealed significant gait improvement regarding stability, speed and stride length ($p < .001$). Based on the Moore and Wolfson criteria, the rating of this study was B.

4 | DISCUSSION

Our study included 6 non-pharmacological interventional protocols regarding the assessment and rehabilitation of CerA in MS. 3 studies were RCTs with significant results and three were pilot studies of which two reached a significant outcome. The interventions were quite heterogeneous and included conventional physiotherapy, robotic visual biofeedback reeducation training, task-oriented training, and functional rehabilitation techniques.

Regarding conventional physiotherapy, several groups have attempted to access its impact on extremity or truncal tremor in patients with ataxia of various pathophysiology. Their findings suggested that there was significant symptom improvement (trunk or extremity tremor) on the specific patient's kinetic features via applying equally distributed external torso weights and dynamic plaster on the extremity with tremor (Ayvat et al., 2018; Miller et al., 2016; Widener et al., 2020). Furthermore, TT programs may improve MS related fatigue, effectively manage Parkinson's related tremor and has an established beneficial impact on Cerebral Palsy patients (Barbagallo et al., 2018; Soke et al., 2021). The application of TT rehabilitation programs has underlined the importance of a multimodal protocol regarding ataxia and tremor where apart from TT, lumbar stabilization, and conventional physiotherapeutic training protocols have been applied (Soke et al., 2021). In particular, the combination of TT with aerobic exercise, has shown to improve balance and gait performance, which could be translated into an increase in functional mobility and quality of life (Barbagallo et al., 2018; Soke et al., 2021). Adaptive robot training through visual biofeedback can further improve upper limb kinematics and functional ability which may reduce limb-tremor in MS patients (Ali et al., 2020; Carpinella et al., 2012). Robotic rehabilitation via manipulation of movement sequence curvature reduces gait incoordination and balance in MS patients (Barbagallo et al., 2018; Vergaro et al., 2010). A systematic review by Milne and colleagues assessed hereditary ataxia and concluded that functional rehabilitation may improve mobility, balance, and ataxia (Gandolfi et al., 2014). Several other groups supported the beneficial effect of specific functional sequences like cycling and dancing in vascular incidents (Da Rosa Pinheiro et al., 2021), Parkinson's (Hackney & Earhart, 2010; Pereira et al., 2019) and Spinocerebellar ataxia (Chang et al., 2015).

Ataxia in MS is quite challenging symptom rehabilitation wise. The means of rehabilitating CerA included the application of an exoskeleton in robotics, the application of a physiotherapy protocol based on Activities of Daily Living (ADL), the adjustment of a recreational activity like cycling and the application of conventional physiotherapy. In all interventions included there were methodological discrepancies (Milne et al. 2017).

Based on the tools applied to assess the gravity of CerA (ICARS), the application of a robotic exoskeleton and evaluation of a probable improvement was limited to MS patients with very serious CerA symptoms, while the application of functional rehabilitation techniques, like cycling, included only patients with very mild CerA clinical phenotypes. Furthermore, the recruitment of MS patients with CerA in one study was not based on kinetic features but on their neuropsychological profile, where the selection was based on the Symbol Digit Modalities test (SDMT) and Montreal Cognitive Assessment (MoCA) scores without providing any supportive evidence of the score cut-off selection (Scheidler et al., 2018). In addition, there were significant methodological limitations regarding the MS clinical parameters. More specifically, in all 6 studies the MS sample was significantly heterogeneous based on EDSS (wide range of EDSS score 0.5–6.5) which resulted in different CerA symptom origin (ataxic symptoms due to clinical relapse vs. ataxic symptoms due to cerebellar cortical atrophy). Hence, the evaluation and rehabilitation of the symptom should have been based on different variables and conditions as defined by the pathological and pathophysiological stage of MS. Furthermore, the MS diagnostic criteria used to acknowledge the disease were also extremely heterogeneous or non-existent. The diagnostic criteria used ranged from 2001 (Keser et al., 2013) to 2010 (The periodic health examination, 1979). Given the fact that the MS diagnostic criteria have evolved, throughout the years, to become more sensitive and time efficient, the use of outdated ones automatically makes the MS patients stratified diagnostically heterogeneous and incomparable (McDonald et al., 2001; Polman et al., 2011). In addition, in 3 studies (Klatt et al., 2019; Rahimibarghani et al., 2022; Salcı et al., 2017) there were no MS diagnostic criteria were applied and the sample stratification was performed based on a biased neurological examination or on the EDSS score. Finally, none of the pilot studies has provided any data on a future RCT study and there was no follow-up data in any of the study protocols included.

Despite the above-described methodological limitations, the results of 5 studies were significant, without however reporting the effect size in all cases, and highlighted a beneficial effect of all the rehabilitation protocols in CerA due to MS. Most of the studies included, highlight the increasing level of difficulty in all exercises performed and that the transition from one kinematic protocol to the other (i.e., Lumbar Stabilization to Task-oriented training) depended on the patient's rate of improvement.

Hence, the authors may conclude that a hypothetical effective rehabilitation protocol regarding CerA due to MS could have included all 3 trainings and techniques starting from Conventional Physiotherapy and NDT-Bobath methodology and moving to Robotic visual Rehabilitation for kinetic program reeducation and then to task-oriented training. This procedure would provide ample time for the ataxic MS patient to familiarize with the reeducated program procedures, before moving to Functional Rehabilitation techniques which demand a higher level of coordination and significantly better balance capabilities. Such a process, although demanding, provides the opportunity to achieve a higher kinetic functional level and by that the possibility to interact anew within the social environment.

5 | CONCLUSION

To our knowledge, this is the most recent systematic review regarding the interventional non-pharmacological rehabilitation protocols of CerA due to MS. It emphasizes on the need for multicentric studies of high quality where all rehabilitation protocols will be available without any demographic, clinical and methodological limitations. CerA in MS requires the acknowledgement of a plethora of different parameters related to both the disease and the versatility of the rehabilitation protocols, to achieve more efficient methods accessing the matter.

AUTHOR CONTRIBUTIONS

All authors approved the submission of the final version of this paper. *Conceptualization*: S.G.; *Data Curation*: V.G.; *Formal Analysis*: K.S.; *Investigation*: A.K.C; *Methodology*: V.G.; *Project Administration*: C.Z.; *Supervision*: Sotirios Giannopoulos, D.M. (equal); *Validation*: M.P. and G.P.P. (equal); *Visualization*: D.K.K and CZ. (equal); *Writing-Original Draft Preparation*: A.K.C. and D.K.K. (equal); *Writing-Review & Editing*: D.K.K., A.K.C. and S.G. (equal).

CONFLICT OF INTEREST STATEMENT

The authors have declared that no competing interests exist.

PEER REVIEW

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REFERENCES

Ali, A. S., Darwish, M. H., Shalaby, N. M., Abbas, R. L., & Soubhy, H. Z. (2020, December). Efficacy of core stability versus task-oriented trainings on balance in ataxic persons with multiple sclerosis. A Single Blinded Randomized Controlled Trial. *Multiple Sclerosis and Related Disorders*, *2021*(50), 102866.

Ayvat, E., Kılınç, Ö. O., Ayvat, F., Sütçü, G., Kılınç, M., Aksoy, S., & Yıldırım, S. A. (2018). The use of goal attainment scaling (GAS) in the rehabilitation of ataxic patients. *Neurological Sciences*, *39*(5), 893–901.

Barbagallo, G. V., Pavone, P., Romano, C., Lubrano, R., & Falsaperla, R. (2018). Department Pediatric Autoimmune Encephalitis. *Massimo*, *13*(2), 176–181.

Carpinella, I., Cattaneo, D., Bertoni, R., & Ferrarin, M. (2012). Robot training of upper limb in multiple sclerosis: Comparing protocols with or without manipulative task components. *IEEE Transactions on Neural Systems and Rehabilitation Engineering.*, *20*(3), 351–360.

Chang, Y. J., Chou, C. C., Huang, W. T., Lu, C. S., Wong, A. M., & Hsu, M. J. (2015). Cycling regimen induces spinal circuitry plasticity and improves leg muscle coordination in individuals with spinocerebellar ataxia. *Archives of Physical Medicine and Rehabilitation*, *96*(6), 1006–1013.

Da Rosa Pinheiro, D. R., Cabeleira, M. E. P., Da Campo, L. A., Correâ, P. S., Blauth, A. H. E. G., & Cechetti, F. (2021). Effects of aerobic cycling training on mobility and functionality of acute stroke subjects: A randomized clinical trial. *NeuroRehabilitation*, *48*(1), 39–47.

Fga, M., & Human, W. C. (2002). Human herpes virus 6 and multiple sclerosis. *Acta Neurologica Scandinavica*, *106*(2), 63–83.

Gandolfi, M., Geroin, C., Picelli, A., Munari, D., Waldner, A., Tamburin, S., Marchioretto, F., & Smania, N. (2014). Robot-assisted vs. sensory integration training in treating gait and balance dysfunctions in patients with multiple sclerosis: A randomized controlled trial. *Frontiers in Human Neuroscience*, *8*(May), 8.

Hackney, M. E., & Earhart, G. M. (2010). Effects of dance on gait and balance in Parkinsons disease: A comparison of partnered and non-partnered dance movement. *Neurorehabilitation and Neural Repair*, *24*(4), 384–392.

Keser, I., Kirdi, N., Meric, A., Kurne, A. T., & Karabudak, R. (2013). Comparing routine neurorehabilitation program with trunk exercises based on bobath concept in multiple sclerosis: Pilot study. *Journal of Rehabilitation Research and Development*, *50*(1), 133–140.

Klatt, B. N., Sparto, P. J., Terhorst, L., Winser, S., Heyman, R., & Whitney, S. L. (2019). Relationship between subjective visual vertical and balance in individuals with multiple sclerosis. *Physiotherapy Research International*, *24*(1), 1–7.

Latimer-Cheung, A. E., Pilutti, L. A., Hicks, A. L., Martin Ginis, K. A., Fenuta, A. M., MacKibbon, K. A., et al. (2013). Effects of exercise training on fitness, mobility, fatigue, and health-related quality of life among adults with multiple sclerosis: A systematic review to inform guideline development. *Archives of Physical Medicine and Rehabilitation*, *94*(9), 1800–1828.e3.

McDonald, W. I., Compston, A., Edan, G., Goodkin, D., Hartung, H. P., Lublin, F. D., et al. (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.

Miller, L., Van Wijck, F., Lamont, L., Preston, J., & Hair, M. (2016). Sensory dynamic orthoses in mild to moderate upper limb tremor in multiple sclerosis: A mixed methods feasibility study. *Clinical Rehabilitation*, *30*(11), 1060–1073.

Milne, S. C., Corben, L. A., Georgiou-Karistianis, N., Delatycki, M. B., & Yiu, E. M. (2017). Rehabilitation for individuals with genetic degenerative ataxia: A systematic review. *Neurorehabilitation and Neural Repair*, *31*(7), 609–622.

Page, M. J., Moher, D., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., et al. (2021). Research methods and reporting prisma 2020 explanation and elaboration: Updated guidance and exemplars for reporting systematic reviews review findings. *The Preferred*. 372.

Pereira, A. P. S., Marinho, V., Gupta, D., Magalhães, F., Ayres, C., & Teixeira, S. (2019). Music therapy and dance as gait rehabilitation in patients with Parkinson disease: A review of evidence. *Journal of Geriatric Psychiatry and Neurology*, *32*(1), 49–56.

Polman, C. H., Reingold, S. C., Banwell, B., Clanet, M., Cohen, J. A., Filippi, M., Fujihara, K., Havrdova, E., Hutchinson, M., Kappos, L., Lublin, F. D., Montalban, X., O'Connor, P., Sandberg-Wollheim, M., Thompson, A. J., Waubant, E., Weinshenker, B., & Wolinsky, J. S. (2011). Diagnostic criteria for multiple sclerosis: 2010 revisions to the McDonald criteria. *Annals of Neurology*, *69*(2), 292–302.

Rahimibarghani, S., Emami-Razavi, S. Z., Naser Moghadasi, A., Azadvari, M., Shojaee Fard, M., & Rahimi-Dehgolan, S. (2022). Quantitative changes in gait parameters after cycling among multiple sclerosis patients with ataxia:A pilot study. *Journal of Modern Rehabilitation.*, *16*(4), 355–363.

Salcı, Y., Fil, A., Armutlu, K., Yildiz, F. G., Kurne, A., Aksoy, S., Nurlu, G., & Karabudak, R. (2017). Effects of different exercise modalities on ataxia in multiple sclerosis patients: A randomized controlled study. *Disability and Rehabilitation*, *39*(26), 2626–2632.

Scheidler, A. M., Kinnett-Hopkins, D., Learmonth, Y. C., Motl, R., & López-Ortiz, C. (2018). Targeted ballet program mitigates ataxia and improves balance in females with mild-to-moderate multiple sclerosis. *PLoS One*, *13*(10), 1–16.

Soke, F., Guclu-Gunduz, A., Kocer, B., Fidan, I., & Keskinoglu, P. (2021). Task-oriented circuit training combined with aerobic training improves motor performance and balance in people with Parkinson's disease. *Acta Neurologica Belgica*, *121*(2), 535–543.

Stevens, V., Goodman, K., Rough, K., & Kraft, G. H. (2013). Gait impairment and optimizing mobility in multiple sclerosis. *Physical Medicine and Rehabilitation Clinics of North America*, *24*(4), 573–592.

The periodic health examination (1979). Canadian Task Force on the Periodic Health Examination. *Canadian Medical Association Journal*, *121*(9), 1193–1254.

Vergaro, E., Squeri, V., Brichetto, G., Casadio, M., Morasso, P., Solaro, C., & Sanguineti, V. (2010). Adaptive robot training for the treatment of incoordination in multiple sclerosis. *Journal of NeuroEngineering and Rehabilitation*, *7*(1), 1–11.

Walton C, King R, Rechtman L, Kaye W, Leray E, Marrie RA, Robertson N, la Rocca N, Uitdehaag B, van der Mei I, Wallin M, Helme A, Angood Napier C, Rijke N, Baneke P Rising prevalence of multiple sclerosis worldwide: Insights from the atlas of MS, third edition. *Multiple Sclerosis Journal*. 2020;*26*(14):1816–21.

Widener, G. L., Conley, N., Whiteford, S., Gee, J., Harrell, A., Gibson-Horn, C., Block, V., & Allen, D. D. (2020). Changes in standing stability with balance-based torso-weighting with cerebellar ataxia: A pilot study. *Physiotherapy Research International.*, *25*(1), 1–10.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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