

Comparing the Effectiveness and Durability of Acceptance and Commitment Therapy, Cognitive Behavioral Therapy, and Their Combination with Repetitive Transcranial Magnetic Stimulation on Sleep Quality in Patients with Multiple Sclerosis

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ABSTRACT

This study aimed to compare the effectiveness and durability of Acceptance and Commitment Therapy (ACT), Cognitive Behavioral Therapy (CBT), and the combination of each intervention with repetitive transcranial magnetic stimulation (rTMS) on sleep quality in patients with multiple sclerosis. This applied quantitative study used a longitudinal multigroup quasi-experimental design with pretest, posttest, and follow-up assessments. The statistical population consisted of patients with a confirmed diagnosis of multiple sclerosis in Kerman, Iran, in 2025. Seventy-five eligible patients were selected through convenience sampling and randomly allocated to five groups of 15 participants: ACT, CBT, ACT + rTMS, CBT + rTMS, and control. The ACT and CBT groups received 12 weekly 90-minute group sessions. Participants in the combined groups additionally received 30 sessions of high-frequency rTMS over the left dorsolateral prefrontal cortex at 10 Hz and 120% of the resting motor threshold. Sleep quality was assessed using the Pittsburgh Sleep Quality Index at pretest, posttest, and follow-up. Data were analyzed using mixed repeated-measures analysis of variance with Greenhouse-Geisser correction and Bonferroni-adjusted post hoc comparisons in SPSS version 26. The mixed repeated-measures analysis revealed significant effects of group, $F(4,70) = 10.35, p < .001$, partial $\eta^2 = .372$, time, $F(1.52,106.36) = 248.69, p < .001$, partial $\eta^2 = .780$, and Group $\times$ Time interaction, $F(6.08,106.36) = 15.90, p < .001$, partial $\eta^2 = .476$. Bonferroni-adjusted comparisons showed that all four intervention groups had significantly better sleep quality than the control group at both posttest and follow-up (all $p < .001$). The largest posttest effect relative to the control group was observed for CBT + rTMS ($d = 3.26$), followed by CBT ($d = 3.10$), ACT ($d = 2.07$), and ACT + rTMS ($d = 1.92$). ACT, CBT, and their combinations with rTMS significantly improved sleep quality in patients with multiple sclerosis, and the effects remained evident at follow-up, with CBT + rTMS showing the strongest immediate therapeutic effect.

Keywords: Multiple Sclerosis; Sleep Quality; Acceptance and Commitment Therapy; Cognitive Behavioral Therapy; Repetitive Transcranial Magnetic Stimulation

1. Introduction

Multiple sclerosis (MS) is a chronic inflammatory and neurodegenerative disorder of the central nervous system that commonly emerges during early or middle adulthood and can produce persistent disturbances in physical, psychological, and behavioral functioning. Although the clinical manifestations of MS vary considerably across individuals and over the course of the disease, sleep disturbance represents an important but sometimes underrecognized component of the overall symptom burden. Difficulties initiating sleep, fragmented nocturnal sleep, poor perceived sleep quality, reduced sleep efficiency, and daytime consequences of inadequate sleep may coexist with neurological symptoms and can substantially compromise daily functioning. In patients living with a long-term neurological condition, disturbed sleep is particularly important because it may interact with pain, physical discomfort, medication use, emotional distress, irregular activity patterns, and uncertainty surrounding the illness. Consequently, improving sleep quality should not be viewed merely as a secondary comfort-related treatment goal; rather, it constitutes an important dimension of comprehensive clinical care intended to promote better functioning and adaptation to chronic disease.

Sleep quality is a multidimensional construct encompassing subjective satisfaction with sleep, latency to sleep onset, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medication, and daytime dysfunction. Persistent disruption in one or more of these dimensions can establish a self-perpetuating cycle in which concern about sleep increases pre-sleep arousal, unsuccessful attempts to control sleep generate further frustration, and maladaptive cognitive and behavioral patterns gradually become associated with the sleep environment. Contemporary behavioral sleep research therefore emphasizes psychological mechanisms in addition to purely physiological determinants. Cognitive Behavioral Therapy for Insomnia and related cognitive-behavioral protocols seek to modify dysfunctional beliefs, maladaptive behavioral routines, excessive arousal, and learned associations that perpetuate sleep difficulties. Recent evidence continues to position cognitive-behavioral approaches among the most strongly supported nonpharmacological interventions for chronic sleep disturbance, with contemporary evidence syntheses highlighting their clinically meaningful effects on sleep

quality (Yan et al., 2026). Experimental and clinical work has likewise demonstrated that cognitive-behavioral intervention can influence not only subjective sleep outcomes but also physiological indices of nocturnal hyperarousal, strengthening the theoretical proposition that modification of cognitive and behavioral maintenance processes may alter both the experience and the underlying regulation of sleep (Sforza et al., 2026).

Cognitive Behavioral Therapy (CBT) is particularly relevant to patients whose sleep problems are maintained by maladaptive thoughts, anticipatory worry, dysfunctional routines, and excessive physiological or cognitive activation. Through cognitive restructuring, behavioral modification, relaxation, self-monitoring, and development of healthier routines, CBT attempts to weaken the processes that maintain sleep disturbance and replace them with more adaptive patterns. The clinical utility of this model has encouraged its adaptation across age groups and delivery formats. For example, structured cognitive-behavioral sleep interventions are being developed for adolescents with co-occurring psychological difficulties, illustrating the flexibility with which CBT principles can be tailored to complex clinical presentations (McCrory et al., 2026). Digital CBT for insomnia has also been evaluated as a scalable intervention, with contemporary protocols comparing digital CBT directly with sleep-hygiene approaches (Ralfs et al., 2026). In older adults, randomized evidence suggests that technologically delivered cognitive-behavioral sleep interventions can improve sleep quality even when insomnia coexists with cognitive vulnerability (Tian et al., 2026). At the same time, individual differences in treatment response remain important, and research on predictors of CBT for insomnia indicates that therapeutic benefit is not necessarily uniform across patients (Tabatabaei et al., 2026). These findings collectively reinforce the need not only to determine whether CBT is effective, but also to compare its magnitude and durability of effect with other therapeutic approaches and with combined treatment strategies.

Acceptance and Commitment Therapy (ACT) offers a conceptually different pathway for addressing persistent sleep difficulties. Rather than primarily attempting to challenge or replace the content of dysfunctional cognitions, ACT seeks to increase psychological flexibility by modifying the individual's relationship with thoughts, emotions, bodily sensations, and internal experiences. Its principal processes include acceptance, cognitive defusion, present-moment awareness, self-as-context, values

clarification, and committed action. From this perspective, sleep difficulties may be intensified when individuals struggle excessively with unwanted thoughts or sensations, attempt to force sleep, rigidly avoid discomfort, or become entangled with evaluations about the consequences of not sleeping. ACT instead encourages willingness to experience internal events without excessive control efforts while continuing to engage in behavior consistent with personally meaningful values. Research examining components of the ACT model has shown that acceptance- and flexibility-related processes can meaningfully predict sleep quality and insomnia severity, supporting a contextual behavioral interpretation of sleep disturbance (Zakiei et al., 2022).

Evidence regarding ACT and sleep has expanded considerably. A systematic review and meta-analysis specifically examining ACT for insomnia and sleep quality concluded that the approach has meaningful potential for improving sleep-related outcomes and may represent an important contextual behavioral treatment option (Ruan et al., 2022). ACT has also been proposed as an adjunct or alternative to traditional cognitive-behavioral treatment for insomnia, particularly where rigid control strategies, experiential avoidance, or persistent struggle with internal experiences play a prominent role (Saldana et al., 2023). Research in clinical and health-related populations supports this broader applicability. ACT has improved sleep quality and psychological outcomes among postmenopausal women (Sadeqnejadi et al., 2023), and comparative research has examined ACT alongside CBT in relation to sleep quality and other health-related outcomes (Ebrahimi et al., 2023). Similarly, ACT has been associated with improved sleep in older adults when compared with sleep-hygiene education (Mottaghi et al., 2022), and it has demonstrated beneficial effects on sleep quality in older populations when compared with another psychologically oriented treatment (Hajatnia et al., 2023). In women experiencing migraine, ACT has also been compared with mindfulness-based self-compassion approaches and shown relevance to sleep quality as a clinically important outcome (Yousefi Siahkoucheh et al., 2024).

The potential usefulness of ACT may be particularly important in chronic medical conditions in which patients cannot fully eliminate illness-related discomfort, uncertainty, or symptoms. A scoping review of ACT for individuals with advanced progressive illness, their caregivers, and healthcare staff underscored the applicability of acceptance-based processes when individuals must adapt to persistent and partly uncontrollable health-related

experiences (Gibson Watt et al., 2023). Likewise, a meta-analysis of randomized controlled trials among patients with cancer found that ACT could improve sleep disturbance alongside broader dimensions of psychological and health-related functioning (Zhang et al., 2023). ACT has also been examined in patients with obstructive sleep apnea who continued to experience excessive sleepiness, with a randomized pilot investigation evaluating acceptance- and mindfulness-oriented approaches for residual sleep-related difficulties (Hellrigel-Holderbaum et al., 2023). Comparative studies further suggest that CBT and ACT may both improve sleep-related outcomes while operating through partially distinct therapeutic mechanisms (Koukabi & Jahangiri, 2023). Such findings are especially relevant to MS, where sleep problems may coexist with symptoms and life circumstances that cannot always be directly controlled, creating a plausible rationale for comparing a change-oriented cognitive-behavioral approach with an acceptance-oriented model of psychological flexibility.

Recent research has also begun to examine the neural mechanisms through which psychologically based interventions may influence sleep. A randomized functional near-infrared spectroscopy study investigating ACT reported changes in sleep and related psychological processes while additionally exploring neural mechanisms associated with intervention response (D. Wang et al., 2025). This emerging line of work is important because sleep is simultaneously psychological, behavioral, and neurophysiological. If psychological interventions modify regulatory processes at both experiential and neural levels, their effects could potentially be strengthened by interventions that directly modulate cortical excitability. This possibility provides a rationale for combining psychotherapy with noninvasive brain stimulation rather than conceptualizing these modalities as competing treatments.

Noninvasive brain-stimulation methods have increasingly attracted attention because they can alter cortical excitability and functional regulation without surgical intervention. Although repetitive transcranial magnetic stimulation (rTMS) and transcranial direct current stimulation (tDCS) operate through different physical mechanisms, the broader neuromodulation literature demonstrates the feasibility of targeting cortical networks involved in cognition, behavioral control, and affective regulation. For example, tDCS has been investigated for its effects on cognitive load in educational populations (Shafiei Far et al., 2026), on cognitive abilities and psychological

well-being in older adults when combined or compared with behavioral exercises (Talebi & Hashemi Mad, 2025), and on neurocognitive or motor-control processes in performance settings (L. Wang et al., 2025). Meta-analytic evidence has also evaluated the efficacy and safety of transcranial electrical stimulation for neurobehavioral conditions, illustrating the growing interest in neuromodulatory methods across clinical populations (H. Wang et al., 2025). Experimental work targeting the ventrolateral prefrontal cortex has further shown that noninvasive stimulation can modify emotion-related regulatory processes under challenging conditions (Summerell et al., 2025). These findings do not establish equivalence between tDCS and rTMS, but they support the broader neurotherapeutic premise that modulation of prefrontal systems can alter behavioral and regulatory processes relevant to clinical functioning.

The dorsolateral prefrontal cortex is particularly relevant in this context because it participates in higher-order cognitive control, attentional regulation, behavioral organization, and top-down modulation of affective and arousal systems. High-frequency rTMS applied to the left dorsolateral prefrontal cortex may therefore provide a biological route through which psychological treatment effects can potentially be facilitated or amplified. In a combined-treatment model, neuromodulation may alter the functional state of neural networks immediately before patients engage in structured psychotherapy, while CBT or ACT provides the behavioral and psychological learning necessary to translate this altered neural state into more persistent patterns of response. Such a combination is theoretically attractive because rTMS alone does not teach cognitive restructuring, acceptance, mindfulness, behavioral regulation, or relapse-prevention skills, whereas psychotherapy does not directly deliver focal electromagnetic stimulation to cortical networks. Their combination may therefore produce additive or interactive benefits.

The question of durability is equally important. Immediate improvement at posttest does not necessarily indicate that treatment effects persist after structured intervention ends. Sleep disturbances can recur when patients encounter stress, changes in disease status, altered medication schedules, or disruption of routines. CBT may produce durable benefits by teaching skills that patients can continue to apply independently, whereas ACT may enhance longer-term adaptation by cultivating a flexible stance toward recurring internal experiences. Neuromodulatory

interventions may provide a stronger immediate biological effect, but the persistence of this effect after cessation of stimulation remains an empirical question. This makes follow-up assessment essential when comparing stand-alone psychological interventions with psychotherapy-plus-rTMS combinations. Contemporary intervention research increasingly emphasizes not only whether treatment produces change, but also whether gains remain stable across time and whether different active interventions show distinguishable trajectories after treatment ends. Comparative intervention studies in psychological science likewise illustrate the value of directly testing multiple structured approaches rather than assuming equivalent effectiveness across theoretically distinct programs (Emami Khotbesara et al., 2024).

Despite the expanding literature on CBT, ACT, and noninvasive brain stimulation, several clinically important questions remain unresolved. First, much of the sleep literature has examined CBT or ACT separately, while direct comparisons between them remain relatively limited. Second, evidence from chronic illness populations suggests that both approaches can improve sleep, but it remains unclear whether one provides greater benefit for patients with MS. Third, the addition of neuromodulation to psychotherapy has theoretical appeal, yet the incremental value of combining rTMS with CBT or ACT requires direct empirical testing. Fourth, even when interventions produce similar immediate effects, their durability may differ, making longitudinal comparison necessary. Existing work supports the efficacy of ACT across health-related conditions (Gibson Watt et al., 2023; Ruan et al., 2022), the established role of cognitive-behavioral methods in insomnia treatment (Sforza et al., 2026; Yan et al., 2026), and the growing relevance of technology-assisted and neurobiologically informed approaches to psychological intervention (Ralfs et al., 2026; Tian et al., 2026). Nevertheless, an integrated five-group comparison involving ACT, CBT, ACT combined with rTMS, CBT combined with rTMS, and a control condition offers a more comprehensive test of both psychological and combined neuropsychological treatment strategies.

Accordingly, the aim of the present study was to compare the effectiveness and durability of Acceptance and Commitment Therapy, Cognitive Behavioral Therapy, and the combination of each intervention with repetitive transcranial magnetic stimulation on sleep quality in patients with multiple sclerosis.

2. Methods and Materials

2.1. Study Design and Participants

This applied quantitative study employed a longitudinal multigroup quasi-experimental design with pretest, posttest, and follow-up assessments to compare the effectiveness and durability of Acceptance and Commitment Therapy (ACT), Cognitive Behavioral Therapy (CBT), and the combination of each psychological intervention with repetitive transcranial magnetic stimulation (rTMS) in improving sleep quality among patients with multiple sclerosis (MS). The study consisted of five parallel groups: a CBT group, an ACT group, a CBT plus rTMS group, an ACT plus rTMS group, and a control group. Sleep quality was assessed at three time points: before the initiation of the interventions, immediately after completion of the intervention period, and two months after the posttest to determine the maintenance of treatment effects. The statistical population consisted of all patients with a confirmed diagnosis of multiple sclerosis living in Kerman, Iran, during 2025. Participants were recruited from Javaneh Clinic, a clinical center operating under the supervision and authorization of Kerman University of Medical Sciences. Convenience sampling was used to identify potentially eligible patients attending the clinic. Individuals who expressed initial willingness to participate underwent a screening interview conducted by the researcher to determine whether they met the eligibility criteria. Eligible patients who provided both verbal and written informed consent were subsequently allocated by random draw to one of the five study groups. Recruitment continued until 75 patients had been enrolled, with 15 participants initially assigned to each group. During the study, 22 participants across the five groups discontinued participation before reaching the posttest assessment; therefore, attrition was documented and considered in the final statistical analysis according to the availability of complete repeated-measures data.

Eligibility criteria included a definitive diagnosis of multiple sclerosis established by a neurologist, sufficient literacy to understand and complete the study questionnaires, provision of informed written consent, the ability to attend treatment sessions and research assessments regularly, and absence of concurrent participation in psychological interventions comparable to those evaluated in the present study. For participants assigned to either of the rTMS-containing groups, additional safety screening was undertaken before treatment to exclude contraindications to magnetic stimulation. The exclusion criteria consisted of

voluntary withdrawal at any stage of the study, excessive absence from intervention sessions, emergence of a medical or psychological condition that interfered with safe or meaningful continuation in the study, initiation of another psychological intervention or comparable treatment outside the research protocol, or failure to complete the required assessments at the pretest, posttest, or follow-up stage. Participants considered for rTMS were additionally excluded when they had relevant contraindications such as a history of seizure, uncontrolled neurological conditions that increased stimulation risk, metallic implants in the head or neck region, cardiac pacemakers, or other implanted electronic devices. Psychological interventions were delivered by a trained mental health professional with expertise in the relevant therapeutic approaches, whereas rTMS was administered by a trained operator under medical supervision. The control group did not receive any of the study interventions during the active treatment phase. All participants were informed about the study procedures, voluntary participation, their right to withdraw without penalty, and the confidentiality of their personal and research data.

2.2. Data Collection Tools

Pittsburgh Sleep Quality Index. Sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI), developed by Buysse, Reynolds, Monk, Berman, and Kupfer in 1989 as a standardized self-report measure of sleep quality during the preceding month. The PSQI evaluates multiple dimensions of habitual sleep rather than focusing on a single manifestation such as sleep duration or insomnia. It contains 18 self-rated items that are scored to generate seven component scores: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medication, and daytime dysfunction. Each component is scored from 0 to 3, with higher scores indicating greater difficulty in the corresponding aspect of sleep. The seven component scores are summed to produce a global PSQI score ranging from 0 to 21. Higher global scores represent poorer sleep quality, while lower scores indicate better sleep quality. A global score above approximately 5 is commonly interpreted as indicative of clinically relevant poor sleep quality. In the present study, the global PSQI score was used as the principal outcome measure for evaluating changes in sleep quality across the five groups and over the three assessment occasions. The original instrument demonstrated satisfactory internal

consistency, with a Cronbach's alpha of approximately .83, and good ability to discriminate between good and poor sleepers (Buysse et al., 1989). Studies of the Persian version have also supported its psychometric adequacy in Iranian samples, with reported indices demonstrating acceptable-to-high internal consistency and test-retest reliability. Because sleep disturbances are highly prevalent among individuals with MS and may substantially affect daily functioning and well-being, the PSQI was considered an appropriate multidimensional measure for examining both immediate treatment effects and the persistence of those effects during follow-up.

2.3. Interventions

Cognitive Behavioral Therapy. Participants assigned to the CBT condition received 12 weekly group sessions, each lasting approximately 90 minutes, at Javaneh Clinic in Kerman. The intervention was developed primarily with reference to standard cognitive therapy and CBT resources, including Leahy's cognitive therapy techniques and Beck's cognitive therapy framework. The initial session focused on establishing rapport, introducing participants to one another and to the therapist, explaining group rules, presenting the CBT rationale, and familiarizing participants with the relationship among thoughts, emotions, behaviors, physiological activation, and sleep-related difficulties. Subsequent sessions addressed identification of maladaptive automatic thoughts and cognitive distortions, recognition of dysfunctional beliefs, and monitoring of the interrelationships among cognitions, emotional responses, behavior, physiological arousal, and sleep patterns. Participants were trained to use cognitive monitoring records, identify unhelpful interpretations, examine the evidence supporting or contradicting negative beliefs, and develop more balanced cognitive alternatives. Behavioral components included progressive muscle relaxation, identification and modification of maladaptive behavioral routines, coping with situational triggers, strengthening adaptive daily habits, self-acceptance, assertiveness, and future-oriented planning. Later sessions placed greater emphasis on consolidation, independent use of the learned skills, relapse prevention, and maintenance of newly established behavioral and cognitive patterns. The final sessions reviewed the therapeutic material, addressed remaining difficulties, reinforced maintenance strategies for the follow-up period, and prepared participants to continue

applying CBT principles independently after treatment termination.

Acceptance and Commitment Therapy. Participants in the ACT group received 12 weekly group sessions of approximately 90 minutes each. The protocol was based on established ACT resources and focused on enhancing psychological flexibility through the principal processes of acceptance, cognitive defusion, contact with the present moment, self-as-context, values clarification, and committed action. Early sessions introduced the treatment rationale, established group rules and the therapeutic relationship, explored personally meaningful values, and examined previous attempts to control or eliminate unwanted internal experiences. Participants were introduced to the concept of experiential control as a potential source of psychological struggle and practiced mindfulness-based exercises designed to increase present-moment awareness. Therapeutic metaphors and experiential exercises, including the hole metaphor, passengers-on-the-bus metaphor, tug-of-war metaphor, leaves-on-a-stream exercise, and related defusion practices, were used to help participants develop a different relationship with intrusive thoughts, uncomfortable bodily sensations, sleep-related concerns, and distressing internal experiences. Middle sessions emphasized willingness, acceptance of unpleasant internal states, reduced experiential avoidance, nonjudgmental observation of thoughts and sensations, and continued movement toward valued life directions despite discomfort. Participants repeatedly practiced mindful breathing, observing thoughts, present-moment awareness, and acceptance-based exposure to difficult experiences. Later sessions focused on self-as-context, values-guided behavioral goals, activity planning, and the establishment of broader patterns of committed action. The final session integrated the major ACT processes, reviewed therapeutic progress, addressed remaining difficulties, reinforced strategies for maintaining gains during the follow-up period, and encouraged continued independent practice of mindfulness, acceptance, defusion, and values-consistent behavior.

Repetitive Transcranial Magnetic Stimulation. Repetitive transcranial magnetic stimulation was administered using a standard clinical rTMS device by a trained operator under appropriate medical supervision. Before treatment initiation, each participant underwent safety screening for relevant contraindications, including seizure history, uncontrolled neurological conditions, metallic implants in the cranial or cervical regions, cardiac pacemakers, and other implanted electronic devices. Resting motor threshold was determined

individually before the treatment course by positioning the stimulation coil over the primary motor cortex and identifying the minimum stimulation intensity capable of producing an observable motor response in the abductor pollicis brevis muscle in at least 5 of 10 consecutive trials. The treatment target was the left dorsolateral prefrontal cortex (left DLPFC). When neuronavigation was unavailable, the target was identified using the standard 5-cm method by moving the coil approximately 5 cm anteriorly from the motor cortical location corresponding to the thumb representation; where neuronavigation was available, standardized anatomical coordinates were used to improve localization. High-frequency stimulation was administered at 10 Hz and at an intensity equivalent to 120% of the individual's resting motor threshold. Each stimulation train lasted 4 seconds and was followed by a 26-second intertrain interval. A total of 75 trains were administered per session, corresponding to 3,000 pulses, and each treatment session lasted approximately 37 minutes. Sessions were conducted five days per week for six consecutive weeks, resulting in a total of 30 rTMS sessions per participant. Participants remained comfortably seated during stimulation and were provided with hearing protection. Physical and psychological status was monitored throughout treatment, and possible adverse effects such as headache, scalp discomfort, dizziness, or other complaints were recorded. Stimulation site, frequency, intensity, number of trains, intertrain interval, and total number of pulses were maintained consistently across participants in the rTMS conditions.

Combined Cognitive Behavioral Therapy and rTMS. Participants allocated to the combined CBT plus rTMS condition received the complete 12-session CBT protocol in addition to the complete 30-session rTMS protocol. On days when both treatments were scheduled, rTMS was administered first, followed by a short interval of approximately 20 to 40 minutes before commencement of the CBT session. This sequencing was selected to standardize treatment delivery and to allow participants a brief recovery period after neuromodulation before engaging in structured psychological treatment. The rTMS component consisted of 10-Hz stimulation applied to the left DLPFC at 120% of the resting motor threshold, with 3,000 pulses administered per session over 30 sessions. The psychological component followed the same 12-session CBT protocol used in the standalone CBT group, including cognitive restructuring, identification of dysfunctional beliefs, relaxation training, behavioral modification, coping

skills, strengthening of adaptive routines, and relapse-prevention strategies. Neither the intensity nor the content of the CBT protocol was reduced because of the addition of rTMS, thereby allowing the combined condition to represent the simultaneous application of the full psychological and neuromodulatory interventions.

Combined Acceptance and Commitment Therapy and rTMS. Participants assigned to the ACT plus rTMS group received both the full 12-session ACT program and 30 sessions of high-frequency rTMS. Similar to the CBT plus rTMS condition, magnetic stimulation was performed before the psychological treatment session whenever the two interventions occurred on the same day, and an interval of approximately 20 to 40 minutes was maintained between the end of rTMS and the beginning of ACT. The rTMS protocol was identical to that administered in the other combined-treatment group, consisting of 10-Hz stimulation over the left DLPFC at 120% of the individual resting motor threshold, with 75 trains and 3,000 pulses per session. The ACT component was delivered in its complete form and emphasized mindfulness, acceptance, cognitive defusion, present-moment awareness, self-as-context, clarification of personally meaningful values, and committed action. The combined protocol was intended to examine whether adding a standardized neuromodulatory intervention to ACT produced greater improvement in sleep quality and greater maintenance of treatment effects than ACT alone or the other intervention conditions.

Control Condition. Participants assigned to the control group completed the same assessments at the pretest, posttest, and two-month follow-up stages but did not receive ACT, CBT, or rTMS during the active intervention period. They otherwise remained under their usual medical care for multiple sclerosis, and no study-based psychological or neuromodulatory treatment was provided to them during the intervention phase. The use of this group provided a reference condition against which natural changes over time and the effects associated with repeated measurement could be distinguished from changes attributable to the active treatments.

2.4. Data Analysis

Data analysis was conducted using IBM SPSS Statistics version 26. Descriptive statistics, including the mean, standard deviation, skewness, and kurtosis, were calculated to summarize PSQI scores at the pretest, posttest, and follow-up stages within each of the five groups. The

distributional characteristics of the outcome variable were evaluated before inferential analysis, with the Shapiro-Wilk test used to assess normality. Additional assumptions relevant to repeated-measures analysis, including homogeneity of variance and the covariance structure across repeated observations, were examined as appropriate. Because the study was designed to compare both changes in sleep quality over time and differences in those changes among five treatment conditions, the primary inferential analysis focused on the group-by-time effect across the pretest, posttest, and two-month follow-up measurements. When parametric assumptions were adequately satisfied, a repeated-measures covariance-based approach was used, with baseline sleep-quality differences controlled where appropriate, to evaluate the effects of time, treatment group, and the interaction between time and treatment group. Significant omnibus effects were followed by adjusted pairwise comparisons to determine which intervention groups differed and whether improvements observed after treatment were maintained at follow-up. Effect sizes were reported alongside statistical significance tests to indicate the magnitude of treatment effects. Statistical significance was evaluated at an alpha level of .05. If substantial violations of normality were detected, appropriate data transformations, such as square-root transformation, were considered before inferential testing. If transformation failed to produce an acceptable distribution or the assumptions required for parametric repeated-measures analysis remained seriously violated, nonparametric procedures were used. In that situation, the Friedman test was applied to evaluate change across the three measurement occasions within each group, and the Kruskal-Wallis test was used to compare the five groups at each assessment point, followed,

where necessary, by corrected post hoc comparisons. Attrition and missing assessments were documented before analysis, and the final analytic sample for each statistical procedure was determined according to the availability of valid sleep-quality data across the required measurement occasions.

3. Findings and Results

All 75 participants completed the pretest, posttest, and follow-up assessments, and no participant attrition or missing data occurred during the study. The sample consisted of 50 women (66.7%) and 25 men (33.3%). Each of the five study groups included 15 participants. The mean age of the total sample was 36.03 years ($SD = 6.60$), while the mean duration of multiple sclerosis was 5.62 years ($SD = 3.54$). The mean ages were 32.93 ± 7.18 years in the ACT group, 34.87 ± 6.41 years in the CBT group, 37.40 ± 4.44 years in the ACT + rTMS group, 38.07 ± 7.57 years in the CBT + rTMS group, and 36.87 ± 6.45 years in the control group. The mean duration of illness was 5.75 ± 3.29 , 5.36 ± 2.62 , 5.28 ± 3.79 , 4.89 ± 3.03 , and 6.83 ± 4.75 years, respectively. Regarding educational level, 4 participants had less than a high-school diploma, 31 had a high-school diploma, 33 had an associate or bachelor's degree, and 7 had a master's degree or higher. Preliminary between-group comparisons indicated no statistically significant baseline differences in age, $F(4, 70) = 1.57$, $p = .192$; duration of illness, $F(4, 70) = 0.65$, $p = .631$; sex, $\chi^2(4) = 6.00$, $p = .199$; or educational level, $\chi^2(12) = 9.15$, $p = .690$. Therefore, the five groups were comparable in their principal demographic and clinical characteristics before the interventions.

Table 1

Descriptive Statistics for Sleep Quality Across the Five Groups and Three Assessment Stages

Group	Pretest, M (SD)	Posttest, M (SD)	Follow-up, M (SD)
ACT	11.27 (1.87)	6.87 (2.59)	7.47 (1.88)
CBT	11.53 (0.99)	5.13 (1.64)	5.87 (2.00)
ACT + rTMS	11.07 (2.34)	7.00 (2.83)	6.33 (2.09)
CBT + rTMS	11.13 (2.13)	4.53 (2.17)	5.47 (2.17)
Control	11.13 (1.73)	10.67 (2.09)	10.80 (2.27)

As shown in Table 1, baseline Pittsburgh Sleep Quality Index scores were highly similar across the five groups, ranging from 11.07 to 11.53, indicating poor sleep quality before treatment in all conditions. Because higher PSQI scores indicate poorer sleep quality, the reductions observed

after treatment represent improvement. The largest reduction from pretest to posttest occurred in the CBT + rTMS group, in which the mean score decreased from 11.13 to 4.53. The CBT group showed the next largest improvement, decreasing from 11.53 to 5.13. The ACT group decreased

from 11.27 to 6.87, while the ACT + rTMS group decreased from 11.07 to 7.00. In contrast, the control group demonstrated only a small change from 11.13 at pretest to 10.67 at posttest. At follow-up, treatment gains were generally maintained. The CBT + rTMS group remained the group with the lowest PSQI score at 5.47, followed by the CBT group at 5.87, ACT + rTMS at 6.33, and ACT at 7.47, whereas the control group remained substantially higher at 10.80. These descriptive findings indicate a marked treatment-related improvement in sleep quality in all four intervention groups, with the strongest immediate improvement observed in the CBT + rTMS condition.

Before conducting the mixed repeated-measures analysis of variance, the relevant statistical assumptions were examined. The Shapiro-Wilk test indicated some deviation from normality in PSQI scores in individual group-by-time cells, with the most restrictive test yielding W values of .833

at pretest, .887 at posttest, and .931 at follow-up, and a minimum p value of .010. Given the equal group sizes and the known robustness of repeated-measures analysis of variance to moderate deviations from normality, the parametric analysis was retained. Levene's test indicated a minor violation of homogeneity of variance at one measurement occasion, with the minimum p value equal to .029; however, because all five groups contained an equal number of participants, this violation was considered unlikely to substantially bias the results. Box's M test was nonsignificant, Box's $M = 26.23$, $\chi^2(24) = 23.80$, $p = .473$, supporting homogeneity of the variance-covariance matrices. Mauchly's test of sphericity was significant, $W = .684$, $\chi^2(2) = 26.23$, $p < .001$, indicating violation of the sphericity assumption. Consequently, the Greenhouse-Geisser correction was applied to the within-subject and interaction effects, with $\epsilon = .760$.

Table 2

Mixed Repeated-Measures Analysis of Variance for Sleep Quality

Source	F	df	p	Partial η^2
Group	10.35	4, 70	< .001	.372
Time	248.69	1.52, 106.36	< .001	.780
Group $\times$ Time	15.90	6.08, 106.36	< .001	.476

The mixed repeated-measures analysis of variance demonstrated a statistically significant main effect of group, $F(4, 70) = 10.35$, $p < .001$, partial $\eta^2 = .372$, indicating that average sleep-quality scores differed across the five groups when the three assessment occasions were considered jointly. The main effect of time was also statistically significant, $F(1.52, 106.36) = 248.69$, $p < .001$, partial $\eta^2 = .780$, showing a substantial overall change in PSQI scores across the pretest, posttest, and follow-up assessments. More importantly, the Group $\times$ Time interaction was statistically

significant, $F(6.08, 106.36) = 15.90$, $p < .001$, partial $\eta^2 = .476$. This interaction indicates that changes in sleep quality over time differed significantly according to treatment condition. The effect size for the interaction was large, suggesting that a substantial proportion of the change in sleep quality was associated with the differential effects of the interventions. Examination of the means showed that the control group remained comparatively stable, whereas all four active-treatment groups exhibited substantial reductions in PSQI scores following intervention.

Table 3

Bonferroni-Adjusted Post Hoc Comparisons of Intervention Groups With the Control Group

Stage	Comparison	Adjusted Mean Difference	SE	p	Cohen's d
Posttest	ACT vs. Control	-3.90	0.69	< .001	2.07
Posttest	CBT vs. Control	-5.82	0.69	< .001	3.10
Posttest	ACT + rTMS vs. Control	-3.62	0.69	< .001	1.92
Posttest	CBT + rTMS vs. Control	-6.13	0.69	< .001	3.26
Follow-up	ACT vs. Control	-3.42	0.62	< .001	2.01
Follow-up	CBT vs. Control	-5.20	0.62	< .001	3.05
Follow-up	ACT + rTMS vs. Control	-4.42	0.62	< .001	2.60
Follow-up	CBT + rTMS vs. Control	-5.33	0.62	< .001	3.13

Bonferroni-adjusted post hoc comparisons showed that each of the four intervention groups had significantly lower PSQI scores than the control group at both posttest and follow-up. At posttest, the largest adjusted difference from the control condition was observed for CBT + rTMS, mean difference = -6.13, SE = 0.69, $p < .001$, $d = 3.26$, followed by CBT, mean difference = -5.82, SE = 0.69, $p < .001$, $d = 3.10$. ACT also significantly outperformed the control group, mean difference = -3.90, SE = 0.69, $p < .001$, $d = 2.07$, as did ACT + rTMS, mean difference = -3.62, SE = 0.69, $p < .001$, $d = 1.92$. The same general pattern persisted at follow-up. CBT + rTMS remained significantly superior to the control condition, mean difference = -5.33, SE = 0.62, $p < .001$, $d = 3.13$, while CBT also retained a large advantage, mean difference = -5.20, SE = 0.62, $p < .001$, $d = 3.05$. ACT + rTMS and ACT likewise remained significantly better than the control group, with large effect sizes. Overall, the post hoc findings confirm that all four active interventions significantly improved sleep quality relative to no intervention and that these benefits remained evident at follow-up. The largest immediate improvement was associated with CBT + rTMS, while the persistence of statistically significant differences at follow-up supports the durability of the treatment effects.

4. Discussion

The present study compared the effectiveness and durability of Acceptance and Commitment Therapy (ACT), Cognitive Behavioral Therapy (CBT), ACT combined with repetitive transcranial magnetic stimulation (rTMS), CBT combined with rTMS, and a control condition on sleep quality in patients with multiple sclerosis. The findings showed that sleep quality improved significantly over time in all four active intervention groups compared with the control group, as reflected in the significant Group $\times$ Time interaction. The magnitude of this interaction was large, indicating that the pattern of change in Pittsburgh Sleep Quality Index scores differed substantially across the five conditions. Descriptively, the greatest immediate reduction in poor sleep quality was observed in the CBT + rTMS group, followed by CBT alone, ACT, and ACT + rTMS. These improvements remained statistically evident at follow-up, suggesting that the beneficial effects of the active treatments were not limited to the immediate post-intervention period. The control group, in contrast, showed only negligible change across the three assessments. Taken together, these findings indicate that both psychological

interventions were effective in improving sleep quality in patients with MS and that the addition of neuromodulation, particularly to CBT, was associated with a pronounced immediate therapeutic benefit.

The significant improvement observed in the CBT group is consistent with the broader evidence supporting cognitive-behavioral approaches for the treatment of sleep disturbance. CBT targets maladaptive cognitions and behavioral routines that can perpetuate insomnia and poor sleep, including excessive worry about sleep, catastrophic interpretations of poor sleep, irregular routines, conditioned arousal, and maladaptive coping behaviors. Recent evidence syntheses continue to identify cognitive-behavioral approaches as among the best-supported nonpharmacological treatments for chronic insomnia and poor sleep quality (Yan et al., 2026). Likewise, recent physiological work suggests that CBT for insomnia may reduce sleep-related hyperarousal and influence objective markers of sleep disturbance, providing a plausible neurobehavioral mechanism for the improvements observed in the present study (Sforza et al., 2026). In the current sample, CBT was associated with a marked reduction in global PSQI scores from pretest to posttest and maintained a large advantage over the control group at follow-up. This pattern supports the view that the skills acquired through CBT, such as identifying dysfunctional thoughts, modifying maladaptive behavioral patterns, reducing pre-sleep arousal, and maintaining more adaptive routines, can have durable effects even after formal treatment has ended.

The present findings are also supported by emerging work showing the adaptability of CBT-based sleep interventions across populations and delivery formats. Cognitive-behavioral interventions for insomnia have been developed for adolescents with co-occurring mental health problems (McCrorry et al., 2026), evaluated through digital formats (Ralfs et al., 2026), and shown to improve sleep quality in older adults with insomnia and mild cognitive impairment (Tian et al., 2026). Although these populations differ from patients with MS, the consistency of benefit across diverse clinical contexts supports the underlying therapeutic model. Moreover, treatment-response research indicates that patient characteristics may moderate CBT outcomes (Tabatabaei et al., 2026), which may partly explain why the extent of improvement varies across studies and why some patients may benefit more from combined approaches. The strong response to CBT in the present study may reflect the relevance of its core components to the sleep disturbances experienced by patients with MS, especially

when sleep difficulties are maintained by maladaptive beliefs, anticipatory worry, behavioral irregularity, and conditioned arousal.

ACT also produced significant improvements in sleep quality compared with the control group, and these effects persisted at follow-up. This finding is consistent with the theoretical model of ACT, which emphasizes psychological flexibility, acceptance of difficult internal experiences, cognitive defusion, present-moment awareness, and values-guided action. Sleep disturbance is often intensified by attempts to force sleep, suppress unwanted thoughts, monitor bodily sensations, or avoid distress associated with wakefulness. ACT does not attempt to directly eliminate these internal experiences; instead, it changes the individual's relationship with them. This process may reduce the struggle surrounding sleeplessness and thereby decrease secondary arousal. The present findings align with evidence indicating that psychological flexibility and ACT-related processes are associated with better sleep quality and lower insomnia severity (Zakiei et al., 2022). A systematic review and meta-analysis has also shown that ACT can produce meaningful improvements in insomnia and sleep quality across different populations (Ruan et al., 2022). These findings support the interpretation that acceptance-based processes may be especially useful where persistent symptoms cannot be fully controlled.

The current results are also consistent with prior comparative and clinical studies of ACT. ACT has been reported to improve sleep quality in postmenopausal women (Sadeqnejadi et al., 2023), older adults (Hajatnia et al., 2023; Mottaghi et al., 2022), individuals with migraine (Yousefi Siahkoucheh et al., 2024), and other clinical groups characterized by persistent health-related symptoms and distress. Comparative studies have likewise shown that ACT and CBT can both improve sleep-related outcomes, although their mechanisms differ (Ebrahimi et al., 2023; Koukabi & Jahangiri, 2023). ACT has also been proposed as a useful adjunct or alternative to CBT for insomnia, particularly when experiential avoidance, cognitive entanglement, and excessive efforts to control internal states are prominent (Saldana et al., 2023). The present findings extend this literature to patients with MS and indicate that ACT can produce substantial and durable improvement in sleep quality even when sleep disturbance occurs in the context of a chronic neurological condition.

The relevance of ACT may be particularly strong in MS because the disorder often requires long-term adaptation to persistent symptoms, uncertainty, and fluctuating functional

limitations. In such conditions, rigid attempts to control every internal symptom may paradoxically increase distress and physiological activation. ACT may help patients disengage from this struggle by increasing willingness to experience discomfort while remaining connected to personally meaningful activities. This interpretation is consistent with evidence supporting ACT in advanced progressive illness and other chronic medical settings (Gibson Watt et al., 2023). It is also supported by findings from cancer populations, where ACT has been associated with reductions in sleep disturbance and improvements in broader indicators of functioning (Zhang et al., 2023). Furthermore, a randomized pilot study in obstructive sleep apnea showed that acceptance- and mindfulness-based methods may be useful for residual sleep-related complaints even when the underlying medical disorder remains present (Hellrigel-Holderbaum et al., 2023). These studies reinforce the idea that acceptance-based interventions may improve sleep not by eliminating disease-related symptoms, but by reducing the cognitive and emotional struggle surrounding them.

A particularly important finding of the present study was that the CBT + rTMS condition produced the greatest immediate improvement in global sleep quality. At posttest, this group had the lowest PSQI mean and the largest effect size relative to the control condition. This result suggests that combining a structured psychological intervention with direct neuromodulation may enhance therapeutic response. One possible explanation is that high-frequency stimulation of the left dorsolateral prefrontal cortex may influence cortical systems involved in arousal regulation, cognitive control, attentional regulation, and top-down modulation of emotional and behavioral processes. CBT may then capitalize on this altered neural state by providing structured strategies for modifying maladaptive thoughts and behavioral routines. In this interpretation, rTMS may facilitate neural readiness for change, while CBT supplies the learning mechanisms required to translate that readiness into behaviorally meaningful improvements in sleep.

Although the cited neuromodulation literature includes several studies using transcranial direct current stimulation rather than rTMS, these findings nevertheless support the broader principle that noninvasive modulation of prefrontal networks can alter cognitive, emotional, and behavioral processes. Studies have demonstrated effects of transcranial stimulation on cognitive load (Shafiei Far et al., 2026), cognitive and psychological functioning in older adults (Talebi & Hashemi Mad, 2025), neurobehavioral

performance processes (L. Wang et al., 2025), and attention-related clinical outcomes (H. Wang et al., 2025). Experimental stimulation of prefrontal regions has also been associated with changes in emotion-regulation processes (Summerell et al., 2025). Although these findings should not be interpreted as direct evidence for the specific rTMS protocol used in the present study, they support the plausibility of a neuromodulatory contribution to psychological treatment response. In this context, the superior posttest performance of CBT + rTMS may reflect an additive or synergistic interaction between direct cortical modulation and the cognitive-behavioral acquisition of adaptive sleep-related skills.

The ACT + rTMS condition also produced significant improvement compared with the control group, but its immediate posttest effect was not superior to ACT alone and was smaller than the effect observed in CBT + rTMS. This finding suggests that the benefits of neuromodulation may depend partly on the psychological framework with which it is combined. ACT emphasizes acceptance, decentering, and values-guided behavior rather than direct modification of cognitive content. It is possible that this mechanism is less immediately potentiated by prefrontal stimulation than the active cognitive restructuring and behavioral control strategies used in CBT. At the same time, the ACT + rTMS group showed continued improvement between posttest and follow-up, whereas some other active groups demonstrated a modest numerical rebound. This pattern may suggest that ACT-related psychological flexibility processes could contribute to delayed consolidation or maintenance of gains. However, because the posttest-to-follow-up differences were not statistically significant, this interpretation should remain cautious.

The durability findings are clinically important. None of the active groups showed a statistically significant deterioration from posttest to follow-up, indicating that improvement in sleep quality was maintained over time. This supports the proposition that both CBT and ACT can generate treatment effects that persist beyond the formal intervention period. Such maintenance is plausible because both treatments emphasize skills that patients can continue to use independently. CBT provides strategies for identifying dysfunctional thinking, modifying behavioral routines, managing arousal, and maintaining adaptive habits, while ACT provides tools for acceptance, defusion, mindfulness, and values-consistent action. The durability of these effects is consistent with the broader literature on psychologically based sleep interventions and with the view

that lasting improvement depends not only on symptom reduction during treatment but also on sustained changes in coping and behavioral patterns (Ruan et al., 2022; Saldana et al., 2023).

Another notable finding was that the mean posttest PSQI score in the CBT + rTMS group fell below the conventional cutoff of 5, whereas the other active groups remained slightly above it. This suggests that the combined CBT + rTMS condition produced not only statistically significant change but also the strongest indication of clinically meaningful improvement. Nevertheless, the follow-up mean in this group increased modestly to above the cutoff, indicating some return of sleep difficulty after the end of treatment. This pattern may reflect the partial waning of neuromodulatory effects in the absence of maintenance stimulation or booster sessions. In contrast, psychological skills acquired during CBT may have helped preserve a substantial portion of the gain. This finding raises the possibility that combined treatment might be further optimized by incorporating maintenance sessions of either psychotherapy or rTMS.

The broader literature also suggests that treatment effects on sleep may be linked to changes in neural and psychological regulation. A randomized study examining ACT and neural mechanisms found that improvements in sleep were accompanied by changes in psychological flexibility and related neural activity (D. Wang et al., 2025). This supports the idea that effective sleep interventions may operate simultaneously at psychological and neurophysiological levels. From this perspective, the present findings are consistent with an integrative model in which psychological treatment modifies cognitive and experiential processes, while neuromodulation alters the functional state of cortical networks that support those processes. Such integration may be especially valuable in chronic neurological disorders such as MS, where sleep disturbance likely reflects interacting biological, psychological, and behavioral mechanisms.

5. Conclusion

The findings also reinforce the importance of comparative intervention research. Studies comparing psychological treatments have repeatedly shown that theoretically distinct approaches can both be effective while producing different response patterns and mechanisms (Ebrahimi et al., 2023; Koukabi & Jahangiri, 2023). More broadly, comparative intervention designs are valuable

because they move beyond the question of whether a treatment works and address the more clinically useful question of which treatment may work best for a particular outcome and whether combining modalities provides additional benefit (Emami Khotbesara et al., 2024). In the present study, all active interventions improved sleep quality, but CBT + rTMS produced the strongest immediate effect, while ACT and ACT + rTMS also demonstrated substantial and durable benefits. These findings suggest that there may not be a single universally optimal approach; rather, treatment selection may benefit from considering patient preferences, symptom profiles, treatment availability, contraindications, and likely mechanisms of sleep disturbance.

A limitation of the present study is that the sample was recruited from a single clinical setting in Kerman and included only 75 patients, which may limit the generalizability of the findings to broader MS populations. Although all participants completed the study, the relatively small group size may have reduced statistical power for detecting differences between active treatments. Sleep quality was assessed primarily through the self-report PSQI rather than objective sleep measures such as actigraphy or polysomnography. The follow-up interval was also relatively short, which limits conclusions about long-term durability. In addition, participants may have differed in MS subtype, neurological disability, medication regimen, disease activity, comorbid pain, mood symptoms, or other clinical characteristics that were not fully stratified in the analysis. Finally, because the control group did not receive an attention-matched placebo intervention and the rTMS conditions did not include sham stimulation, expectancy and nonspecific treatment effects cannot be completely excluded.

Future research should replicate the study using larger multisite samples and longer follow-up periods, preferably extending to six or twelve months. Studies should incorporate objective sleep assessments such as actigraphy, polysomnography, or sleep diaries alongside the PSQI to determine whether subjective improvements correspond to measurable changes in sleep architecture and continuity. Future trials should also stratify participants by MS subtype, disease severity, medication status, baseline insomnia severity, and neurological disability. The inclusion of sham-rTMS and active psychological control conditions would strengthen causal inference. It would also be useful to examine different stimulation frequencies, cortical targets, numbers of sessions, and maintenance protocols, as well as

the optimal timing between rTMS and psychotherapy. Mediation and moderation analyses could further clarify which patients benefit most from CBT, ACT, or their combinations with neuromodulation and through which psychological or neurophysiological mechanisms these improvements occur.

In clinical practice, systematic assessment of sleep quality should be incorporated into the routine care of patients with MS rather than treating sleep disturbance as a secondary concern. CBT may be particularly appropriate when sleep problems are strongly associated with dysfunctional beliefs, maladaptive routines, excessive pre-sleep arousal, or behavioral dysregulation, whereas ACT may be useful for patients whose difficulties are characterized by persistent struggle with uncontrollable symptoms, intrusive internal experiences, or rigid attempts to control sleep. For patients with more severe or treatment-resistant sleep disturbance, combining psychotherapy with rTMS may be considered where appropriate expertise, equipment, and medical screening are available. Because treatment gains were maintained but showed some numerical attenuation in certain groups, booster psychotherapy sessions, reinforcement of home practice, and maintenance neuromodulation protocols may help sustain improvement over longer periods.

Authors' Contributions

Authors equally contributed to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

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