

1

2

3

4

5

6

7

8

9

10

11

12

13

14

15

16

17

18

19

20

21

22

23

24

25

26

27

28

29

30

31

32

33

34

35

36

37

38

39

40

41

42

43

44

45

46

47

48

49

50

51

52

53

54

55

56

57

58

59

60

Microtesla magnetic therapy for cognitive impairment in long COVID: a randomized pilot study

Running title: Microtesla Magnetic Therapy study

Alexandra Canori, PhD,¹ Eric Watson, PhD,¹ Devanshi Patel, MA,¹ Arianna Fiorentino, MSc,¹
Christopher Santiago, BS,¹ David Maltz, MSE,² Blake Gurfein, PhD,² David Putrino, PhD,^{1*}
Jacqueline Becker, PhD^{3*}

1 Icahn School of Medicine at Mount Sinai, Department of Rehabilitation and Human Performance,
5 E 98th Street, New York, NY 10029 USA
2 Fareon, Inc., 135 Mississippi St, San Francisco, CA 94107 USA
3 Icahn School of Medicine at Mount Sinai, Department of Medicine, 1 Gustave L. Levy Pl, New
York, NY 10029 USA

*David Putrino and Jacqueline Becker contributed equally to this work.

Correspondence to:
David Putrino, PhD
5 E 98th Street SB-18, New York, NY 10029 USA
David.putrino@mountsinai.org

Abstract

Cognitive impairment is common in post-acute sequelae of severe acute respiratory syndrome coronavirus 2 infection (long COVID) and substantially affects function and quality of life. Evidence suggests that sustained neuroinflammation, cerebrovascular dysfunction, and mitochondrial impairment contribute to cognitive symptoms. Microtesla Magnetic Therapy (MMT) is a transcranial, low-amplitude radiofrequency magnetic field intervention that has shown anti-inflammatory and neuroprotective effects in preclinical models, suggesting potential value in long COVID and other neurological disorders. This is the first randomized controlled trial of MMT for long COVID cognitive impairment.

We evaluated the feasibility (primary) and safety (secondary) of at-home MMT in individuals with objective cognitive impairment from long COVID.

Thirty participants were randomized 2:1 to active or sham MMT and self-administered 15-minute treatments at home twice weekly for 4 weeks, with remote monitoring, using a head-worn device delivering a nonthermal radiofrequency magnetic field to the whole brain. Feasibility was defined as completing at least 80% of prescribed treatments and all study visits. Safety was assessed by adverse events. Cognitive function and self-reported mood and quality of life were exploratory outcomes assessed at baseline, Week 4 (post-treatment), and Week 8 (follow-up).

Feasibility was high: all participants who completed the study adhered to 100% of treatments, and usability ratings were strong. No device-related adverse events occurred. Compared with sham, active MMT participants showed significantly greater improvement from baseline to Week 8 in Wechsler Adult Intelligence Scale Digit Span Sequencing ($p = 0.026$), Hopkins Verbal Learning Test-Revised Total Recall ($p = 0.044$), and Delis-Kaplan Executive Function System Color

1
2
3 Naming ($p = 0.049$). Other measures of attention, processing speed, and executive function did not
4
5 differ significantly between groups. Emotional well-being on the 36-Item Short Form Survey
6
7 improved significantly more with active MMT at Week 8 ($p = 0.017$). Depression and anxiety
8
9 decreased in both groups; the anxiety reduction was greater with active treatment in the linear
10
11 mixed-effects model (week $\times$ treatment interaction, $p = 0.038$) but not in the between-group change
12
13 score comparison ($p = 0.057$).
14
15

16
17 At-home MMT was feasible, safe, and well tolerated in individuals with cognitive impairment
18
19 from long COVID. These preliminary, exploratory findings showed nominally significant
20
21 between-group differences favoring active treatment on selected cognitive measures and emotional
22
23 well-being and require confirmation in larger, adequately powered trials.
24
25

26
27
28 **Keywords:** long COVID; cognitive impairment; executive function; magnetic field therapy
29
30
31

32
33
34 **Introduction**
35

36
37 Approximately 10-26% of patients infected with SARS-CoV-2 develop post-acute sequelae of
38
39 COVID-19, or long COVID (LC),¹ a condition characterized by symptoms including fatigue,
40
41 mood changes, sleep disruption, and cognitive impairment that persist at least 3 months following
42
43 acute infection.² The Centers for Disease Control and Prevention (CDC) estimates LC affects 6.4%
44
45 of adults in the United States, which is approximately 17 million individuals.³ Multiple
46
47 pathophysiologic mechanisms have been implicated in the development of LC, such as persistent
48
49 peripheral and central nervous system immune activation, incomplete viral clearance or latent viral
50
51 reservoirs, immune cell exhaustion, vascular and endothelial injury, gut dysbiosis, autoantibody
52
53
54
55
56
57
58
59
60

production, and dysregulated autonomic signaling.⁴⁻⁶ The societal burden of LC is substantial in the United States due to lost productivity, increased healthcare utilization, and reduced quality of life,⁷ with estimated annual costs of approximately \$200 billion.⁸

Cognitive impairment is among the most prevalent and disabling features of LC, with estimates suggesting that 20-30%, or approximately 3-5 million, individuals with LC experience persistent cognitive difficulties.^{9,10} Emerging evidence implicates neuroinflammation as a key underlying driver of cognitive impairment.^{11,12} Specifically, neuroimmune activation and subsequent oxidative stress may perturb mitochondrial bioenergetics and promote a self-perpetuating cycle of energy failure and chronic neuroinflammation, providing a plausible biological basis for persistent cognitive symptoms.¹³ Supporting this framework, several neuroimaging studies have demonstrated microglial activation and elevated inflammatory markers in individuals with LC-related cognitive symptoms.^{14,15} The neurocognitive profile in LC is particularly notable for deficits in executive functioning, attention, and processing speed,¹⁶ which appear to persist over time.¹⁷ Despite growing mechanistic insight, no therapeutic interventions have demonstrated targeted efficacy.

Low-amplitude magnetic field interventions have demonstrated safety and tolerability, with evidence of rapid anti-inflammatory effects in post-surgical clinical studies¹⁸ and animal models of neuroinflammation.¹⁹ Building on this foundation, Microtesla Magnetic Therapy (MMT) was developed as a non-invasive approach to deliver carefully tuned radiofrequency magnetic fields to the brain. Recent preclinical studies showed that MMT suppresses NF- κ B signaling, reduces neuronal reactive oxygen species, and decreases glial activation and lesion burden *in vivo*, producing sustained anti-inflammatory and neuroprotective effects.²⁰ These findings suggest MMT engages redox-sensitive inflammatory networks and modulates neuroimmune activation,

1
2
3 pathways increasingly recognized as central drivers of cognitive dysfunction. As a result, MMT
4
5 represents a promising nonpharmacologic strategy to address a significant unmet clinical need by
6
7 directly targeting neuroinflammatory biology.
8
9

10
11 Based upon the noninvasive, low-amplitude nature of MMT and compelling mechanistic evidence,
12
13 the present study evaluated the feasibility of at-home MMT as a therapeutic intervention for
14
15 individuals with objective cognitive impairment from LC. Our objectives were to (1) assess
16
17 treatment feasibility and acceptability in this population, (2) evaluate the safety and tolerability,
18
19 and (3) collect preliminary efficacy data to inform the design of larger clinical trials. We
20
21 hypothesized that MMT would be feasible and safe in individuals with objective cognitive
22
23 impairment from LC, and that active treatment would demonstrate greater improvements in
24
25 cognitive function and mood symptoms compared to sham treatment.
26
27
28
29
30

31 **Materials and Methods**

32 **Study design**

33
34
35 A prospective, triple-blind, randomized controlled pilot trial of 30 participants with LC and
36
37 objective cognitive impairment was conducted to evaluate the feasibility, safety, and preliminary
38
39 efficacy of MMT. Participants were randomized in a 2:1 ratio to receive either an active or sham
40
41 device. Participants, investigators, and outcome assessors were blinded to group allocation. Device
42
43 assignment was performed by an independent study engineer who pre-programmed active and
44
45 sham devices prior to delivery to the study site, ensuring allocation concealment. Participants were
46
47 asked in a post-intervention survey to indicate whether they believed they had received an active
48
49 or sham device. Blinding integrity was assessed using the index of Petroff et al.²¹ The study
50
51
52
53
54
55
56
57
58
59
60

protocol was approved by the Program for the Protection of Human Subjects at the Icahn School of Medicine at Mount Sinai (STUDY-24-01276) and registered on ClinicalTrials.gov (NCT06739668). All participants provided written informed consent prior to participation.

Study participants

The following inclusion criteria were used to determine participant eligibility: (1) Age 18 years or older, (2) English speaking, (3) SARS-CoV-2 infection documented by laboratory nucleic acid amplification test or antibody test ≥ 6 months from screening, (4) Experiencing symptoms ≥ 6 months that meet LC diagnostic criteria,² (defined as the continuation or new onset of one or more symptoms, including fatigue, post-exertional malaise, cognitive dysfunction, and mood or sleep disturbance, present for at least 6 months following confirmed SARS-CoV-2 infection and not explained by an alternative diagnosis)² (5) Objective cognitive impairment (defined by ≥ 1 standard deviation below the normative mean) on at least one measure of executive functioning (WAIS-IV Digit Span, D-KEFS Color-Word Interference Test, D-KEFS Verbal Fluency, or Trail Making Test Part B), (6) Individuals of childbearing age agreeing to use a highly effective form of birth control, and (7) Willing and able to provide informed consent and attend all study visits.

Exclusion criteria were determined by self-report or review of electronic health record, and included: pre-existing cognitive impairment, current use of immunomodulatory medications, active psychiatric or neurological disorders (defined as a current, unstable, or inadequately treated DSM-5 diagnosis or neurologic disorder identified by self-report), cranially implanted devices or pacemakers, severe head injury within 12 months, SARS-CoV-2 reinfection or vaccination within 30 days prior to the baseline (Visit 1) assessment, diagnosis of immune/autoimmune condition prior to SARS-CoV-2 infection, change in anti-depressant or other psychoactive medication within

1
2
3 90 days, BrainCheck assessment within the last 6 months, febrile at the time of enrollment visit,
4
5 enrollment in another clinical trial within 90 days of study period, inability to achieve appropriate
6
7 positioning of the study device, and pregnancy.
8
9

10 11 **Intervention**

12
13
14 Participants randomized to the active group received treatment with the MMT device, which
15
16 delivers a low-amplitude nonthermal radiofrequency biphasic magnetic field at 27.12 MHz via a
17
18 head-worn applicator (Figure 1). Sham devices were visually identical and had the same indicator
19
20 lights and sounds, but emitted no magnetic field. Participants were trained to self-administer
21
22 treatments at home twice weekly for 15-minute sessions, separated by at least 70 hours, a time
23
24 interval informed by previous *in vivo* studies.²⁰ After each treatment session, the MMT device
25
26 entered a 70-hour lockout period to prevent participants from retreating before the next indicated
27
28 treatment. Due to the high frequency and non-thermal specification of the waveform, active MMT
29
30 did not generate any perceptible sensation to participants.
31
32
33
34
35

36 37 **Study outcomes**

38
39 The primary outcome was feasibility, defined as the proportion of participants completing at least
40
41 80% of scheduled treatments and all three study visits. Additional feasibility measures included
42
43 Device Usability Ratings (Supplementary Table S1) and completeness of data collection.
44
45
46

47 The prespecified secondary outcome was safety. Cognitive performance and self-reported
48
49 symptom (mood, fatigue, and quality of life) changes were exploratory efficacy outcomes.
50
51 Participants completed a structured weekly safety questionnaire in REDCap that captured the
52
53 presence, onset, duration, and severity of any new or worsening symptoms; investigators
54
55
56
57
58
59
60

1
2
3 additionally elicited adverse events through open-ended questioning and clinical evaluation at each
4
5 in-person visit. Adverse events were reviewed by the study team, graded for severity, and
6
7 adjudicated for relatedness to the device and treatment according to ISO 14155 criteria.
8
9

10
11 Objective cognitive performance was assessed with a standardized neurocognitive battery across
12
13 domains, including attention, processing speed, language, memory, and executive functioning.
14
15 Measures included the Wechsler Adult Intelligence Scale Fourth Edition (WAIS-IV) Digit Span,²²
16
17 Hopkins Verbal Learning Test–Revised (HVLT-R),²³ Delis-Kaplan Executive Function System
18
19 (D-KEFS) Color-Word Interference Test,²⁴ D-KEFS Verbal Fluency Test,²⁴ Trail Making Test
20
21 (TMT) Parts A & B,²⁵ Ruff 2 & 7,²⁶ Brief Visuospatial Memory Test (BVM),²⁷ Rey Complex
22
23 Figure Test (RCFT),²⁸ Symbol Digit Modalities Test (SDMT),²⁹ and Multilingual Naming Test
24
25 (MINT).³⁰ All assessments were administered in a fixed order by trained staff to minimize order
26
27 effects and provide consistency across participants.
28
29

30
31
32 Mood and quality of life outcomes were assessed using standardized instruments including the
33
34 Patient Health Questionnaire 9 (PHQ-9),³¹ Generalized Anxiety Disorder 7 (GAD-7),³² DePaul
35
36 Symptom Questionnaire Post-Exertional Malaise (DSQ-PEM),³³ PROMIS Fatigue Short Form-
37
38 7a,³⁴ and 36-Item Short Form Health Survey (SF-36).³⁵ A description of each of these measures is
39
40 provided in Table 1.
41
42

43 44 45 **Study procedures**

46
47
48 Participants attended three in-person visits (Week 0, Week 4, Week 8). At Visit 1, participants
49
50 completed informed consent, medical history review, and baseline cognitive and self-report
51
52 assessments. Participants were trained to use the study device and self-administered the first 15-
53
54 minute treatment under supervision of clinical staff. They were instructed to continue treatments
55
56
57
58
59
60

1
2
3 twice per week at home, separated by at least 70 hours for the 4-week duration of the treatment
4
5 period. Each treatment was scheduled as a video visit with the study team, and a team member
6
7 visually confirmed the accurate positioning of the device and administration of the treatment.
8
9 Participants returned to the study site for Visits 2 and 3 and repeated all assessments conducted at
10
11 baseline to evaluate treatment effects and post-treatment persistence (Figure 2). All visits were
12
13 scheduled at the same time of day to reduce diurnal variability in performance measures. For
14
15 cognitive measures with established alternate forms (e.g., HVLT-R and BVMT), parallel versions
16
17 were administered across visits to reduce practice effects.
18
19
20
21

22 **Data management**

23
24
25
26 The study was monitored by the principal investigator and study staff. All data were entered into
27
28 a 21 CFR 11-compliant electronic data capture system. Treatment adherence, device logs, and
29
30 questionnaire completion were monitored weekly, and self-report safety questionnaires were
31
32 administered weekly to participants during the treatment period and reviewed by the study team.
33
34 Data quality checks were performed regularly to ensure accuracy and completeness.
35
36
37

38 **Statistical analysis**

39 **Feasibility and safety analyses**

40
41
42 Feasibility was assessed by the proportion of participants completing at least 80% of prescribed
43
44 treatments and all scheduled visits. Device usability ratings and responses were summarized. All
45
46 adverse events and complications occurring during the treatment and follow-up periods were
47
48 documented and summarized by treatment group.
49
50
51
52
53
54
55
56
57
58
59
60

Neurocognitive and self-report measures

Neurocognitive instruments and self-report questionnaires were used to evaluate initial efficacy trends between treatment groups from baseline (week 0) to post-treatment (week 4) and from baseline to follow-up (week 8). We emphasize that for efficacy outcomes the study was exploratory and not statistically powered to detect prespecified effect sizes for each endpoint. Clinically meaningful change for neurocognitive assessments of cognitive function was set to 0.5 standard deviations.³⁶ Clinically meaningful change for PHQ-9 and GAD-7 was interpreted as 2 points, aligning with previous studies.³⁷ We fit linear mixed-effects models for all longitudinal outcomes, incorporating treatment, time, and treatment $\times$ time effects. To simplify reporting of the large number of outcomes, the assessments were also evaluated by comparing the average change from baseline between groups using two-sided t-tests assuming unequal variances with p-values reported for directional interpretation. Confidence intervals for the differences between treatment groups are provided for assessment of the observed differences. Cohen's d was calculated as a measure of effect size for select measures. Analyses were conducted using complete-case data; imputation was not used for missing values. Statistical analysis was performed using JMP Pro software (version 19.0).

Results

Participant demographics

A total of 65 participants were recruited and screened; 32 participants failed screening, and 33 were enrolled between December 2024 and October 2025. Reasons for screening exclusion were absence of objective cognitive impairment, current use of immunomodulatory medication, and a

pre-existing serious immune diagnosis (Figure 3). The number of participants on psychoactive medication at baseline by group is reported in Supplementary Table S2. To preserve the randomization allocation and ensure that 30 participants completed all study procedures, screening exceeded the target sample size to account for anticipated attrition. Three study participants were withdrawn from the study after enrollment for the following reasons: (1) COVID reinfection during the study period, which per protocol required withdrawal; (2) Two consecutive video visits missed, which per protocol required withdrawal; (3) Participant injured their ankle and withdrew to pursue surgical intervention. In total, 30 participants with LC-related cognitive impairment completed all trial activities and were analyzed (active = 20; sham = 10). Groups were comparable at baseline with respect to age, education, sex, ethnicity, and time since SARS-CoV-2 infection (Table 2). Differences in race were observed between groups; however, subgroup sizes were small, limiting interpretability. Supplementary Table S3 summarizes medical history by treatment group, including neurological and psychiatric diagnoses and concomitant medications. The proportion of participants classified as cognitively impaired on each neuropsychological test is reported in Supplementary Table S4, along with the baseline between-group comparison for each measure.

Feasibility and safety

This study aimed to determine the feasibility of applying the MMT device for treatment at home. All 30 participants who completed the study received all 8 treatments in accordance with the protocol, although one participant who did not complete the study was withdrawn due to missing two consecutive visits (i.e., 100% adherence). Using the full randomized sample (N=33), 90.9% completed at least 80% of treatments and all study visits. Correct positioning of the device on the head and completion of the full 15-minute treatment duration were confirmed by study staff. Two adverse events occurred in the active treatment group: an ankle injury and SARS-CoV-2

reinfection. Both adverse events were mild and deemed unrelated to treatment. No serious adverse events occurred during this study.

Linear mixed-effects models

Linear mixed-effects models (Supplementary Table S5) identified a significant week $\times$ treatment interaction for GAD-7 ($F(2, 56) = 3.48, p = 0.038$) and the SF-36 Emotional Well-Being subscale ($F(2, 56) = 5.86, p = 0.005$). No other outcome showed a significant interaction; D-KEFS Word Reading showed a significant main effect of treatment ($F(1, 28) = 4.67, p = 0.039$) without an interaction, and 15 of the remaining 22 outcomes showed a significant main effect of week, indicating change over time in both groups without a significant between-group difference in the magnitude of change. The difference-score analyses (Table 3) are reported below, beginning with the two outcomes that showed a significant interaction.

Neurocognitive outcomes

Across multiple neurocognitive domains, between-group differences favored active MMT, with the largest differences observed at the 8-week follow-up (Table 3). Active treatment was associated with larger mean between-group improvements from baseline to Week 8, with small to medium effect sizes observed for working memory (DSS; $d = 0.73, p = 0.026$), verbal learning and memory (HVLRT Total Recall; $d = 0.73, p = 0.044$), and processing speed (D-KEFS Color Naming; $d = 0.62, p = 0.049$); none of these differences remained significant after FDR correction, and none showed a significant week $\times$ treatment interaction in the mixed-effects models (Supplementary Table S5). While the active group showed greater improvements than sham on remaining measures of attention, processing speed, inhibition, and executive function, these differences were not statistically significant (all $p > 0.05$); the corresponding between-group

differences, 95% confidence intervals, and effect sizes are reported in Table 3 and individual participant points and group means are displayed in Supplementary Figure S1. The D-KEFS Category Fluency, RCFT, SDMT, and MINT did not show improvements from baseline to 8 weeks.

Mood and quality of life outcomes

Anxiety (GAD-7) symptoms decreased in both groups; the greater reduction in the active group was significant in the mixed-effects model (Supplementary Table S5) but did not reach statistical significance in the difference-score analysis ($d = -0.83, p = 0.057$).

On the SF-36 Emotional Well-Being (Mental Health) subscale, participants receiving active MMT showed a significantly greater improvement from baseline to Week 8 compared with sham, with a large effect size ($d = 1.31, p = 0.017$, uncorrected). The emotional well-being difference did not remain significant after FDR correction.

Among the outcomes without a significant week $\times$ treatment interaction, depression (PHQ-9) symptoms decreased in both groups over time without a significant between-group difference in the magnitude of change (Table 3). Trending improvements in DSQ-PEM scores were observed in the active treatment group ($d = -0.50, p = 0.296$).

Usability and user experience

Participants reported high usability and satisfaction with the device. Across 12 steps of using the device (from removing the device from the case to putting the device away), two participants indicated a challenge with any step, and three participants indicated a challenge with lifting the device for transport. At least 25/30 participants rated the device as a 4/5 or 5/5 (on a 5-point scale)

for ease of use, comfort, reliability, and convenience. In addition, 24/30 rated their agreement as a 4/5 or 5/5 indicating they would recommend it to others (Supplementary Table S1).

Blinding Integrity

Blinding integrity was assessed using the Petroff index.²¹ This index is simply the difference in the proportion of those guessing they received the active treatment across the two treatment arms and is appropriate for studies in which the randomization is not 1:1. The index ranges from -1 to 1, with 0 indicating perfect blinding. The method assumes all participants provide a guess, however one participant in our sample did not provide a guess. Excluding that participant yielded an index = -0.02 and including that participant with an incorrect guess (worst case) yielded an index = -0.05 (Supplementary Table S6). Both estimates support the blinding integrity of this study.

Discussion

This triple-blind, first-in-human, randomized, sham-controlled study demonstrates that at-home MMT is feasible, safe, and well tolerated in individuals with objective cognitive impairment related to LC. Participants showed 100% treatment compliance and high usability ratings, with no device-related adverse events, indicating strong feasibility and an excellent safety profile for at-home implementation.

MMT treatment was also associated with clinically meaningful improvements in cognition and mood at treatment completion and at 8-week follow-up. Nominally significant (uncorrected) between-group differences favoring active treatment were observed on measures of working memory (Digit Span Sequencing), processing speed (D-KEFS Color Naming), and verbal learning and memory (HVLT-R Total Recall); no differences remained statistically significant after

correction for multiple comparisons. A nominally significant between-group improvement in emotional well-being (SF-36) was also observed, whereas depression and anxiety symptoms declined in both groups (anxiety reductions were greater in the active group in the mixed-effects model, although the between-group difference in change scores did not reach statistical significance). While this exploratory study was not powered for efficacy conclusions, the pattern of differences across several neurocognitive domains and their persistence at follow-up provide preliminary support for the potential clinical value of MMT in addressing an urgent, unmet need in this population (which will require confirmation in adequately powered trials).

The magnitude of cognitive improvement observed with MMT compares favorably to other interventions studied in LC populations.^{38–40} Cognitive rehabilitation approaches have demonstrated modest benefits in pilot studies, with small-to-medium effect sizes and improvements largely limited to self-reported cognitive functioning.^{17,41,42} Pharmacologic interventions targeting cognition in LC remain largely untested in rigorous trials, and those repurposed from other conditions (e.g., stimulants, cholinesterase inhibitors) lack sufficient evidence specific to post-viral populations.^{43,44} Notably, MMT produced improvements across multiple cognitive measures, including processing speed, attention, and memory, suggesting potential for broader cognitive benefit within the very domains impacted in LC. Furthermore, unlike cognitive rehabilitation protocols that require sustained mental effort and may be limited by post-exertional symptom exacerbation, MMT is passive and low-burden, potentially improving accessibility to patients who cannot tolerate effortful interventions. Non-invasive brain stimulation approaches have also been explored in post-COVID populations, including through NIH RECOVER-Neuro⁴⁰ and small trials and case series of transcranial direct current stimulation (tDCS). These studies typically target the dorsolateral prefrontal cortex and have reported

preliminary improvements in fatigue and, less consistently, in cognition.^{45–47} MMT differs from tDCS and other neuromodulation techniques in that it is intended to modulate neuroinflammatory and metabolic signaling rather than to directly stimulate or inhibit neuronal firing.

Mechanistic inferences

The pattern of cognitive improvement observed in this study is consistent with emerging mechanistic models of LC-related cognitive impairment that emphasize persistent neuroinflammation, oxidative stress, and mitochondrial impairment. Between-group differences in working memory (DSS), verbal learning and memory (HVLT-R Total Recall), processing speed (D-KEFS Color Naming), and emotional well-being (SF-36) were larger at 8-week follow-up than immediately post-treatment, suggesting persistence of benefit and durability of treatment effects. It is possible that the delay of these effects suggests a mechanism involving gradual resolution of neuroinflammation and restoration of neuronal and glial function, rather than short-term expectancy effects alone.

This is the first time that an MMT device has been used in a clinical population, and therefore mechanistic understanding is still emerging. Recent preclinical work found that brief exposure to MMT suppressed inflammatory signaling in human immune cells, and repeated transcranial MMT attenuated microgliosis, astrogliosis, immune cell infiltration, and tissue degeneration in a rat model of Parkinson's disease neuroinflammation.²⁰ In this work, MMT also reduced neuronal oxidative stress and improved intrinsic antioxidant capacity, with neuroprotective effects persisting for up to 48 hours following a single exposure.²⁰ The clinical changes observed here are consistent with, but do not demonstrate, the ability of MMT to suppress neuroinflammation, improve mitochondrial function and promote improved regulation of neurons and glia, as these are

all mechanisms of LC-related cognitive loss that have been previously described.^{12,48–50} However, it should be noted that these mechanistic interpretations remain hypothetical.

MMT is distinct from conventional neuromodulation approaches in several important ways. The intervention delivers low amplitude, nonthermal radiofrequency magnetic fields to the whole brain and was developed to target neuroinflammatory signaling and cellular metabolic function, rather than directly stimulate or inhibit neuronal firing through focal electrical, magnetic, or ultrasound stimulation. The therapy is designed for self-administration in the home environment using a head worn device. Automated treatment lockout intervals and remote monitoring supported consistent dosing while minimizing user burden and protocol deviation. These characteristics may enable scalable deployment if efficacy is confirmed, particularly for individuals with chronic illness, fatigue related disability, or limited access to in-person therapy.

Limitations and future implications

This study has several limitations. The small sample size limited statistical power, and multiple outcomes were assessed without correction for multiple comparisons. Findings should be interpreted as exploratory. Additional limitations include possible selection bias arising from screening exclusions and post-randomization withdrawals; a highly educated sample (mean education approximately 17.6 years), which may limit generalizability; a baseline imbalance in racial composition between groups; and the industry funding and device-company involvement in the study. A longer treatment course and follow-up period may be required to fully evaluate efficacy if MMT acts by modulating neuroinflammation, and future adequately powered trials should incorporate mechanistic endpoints, correction for multiplicity, and reporting of the proportion of participants achieving reliable or clinically meaningful change.

Repeated neuropsychological testing can introduce practice effects; however, the sham-controlled design helps minimize this influence, and the domain-specific pattern of improvement along with the greater magnitude of change at delayed follow-up compared to immediately post-treatment suggests that the findings are unlikely to be driven by practice effects alone. Despite these limitations, consistent improvements across neurocognitive domains and mood, the presence of statistically significant and clinically meaningful improvements on certain measures, and the excellent feasibility and safety profile provide a strong rationale for future investigation. These findings may inform the design of larger clinical trials to confirm efficacy and clarify mechanisms.

Conclusions

MMT is a feasible, safe, and well-tolerated nonpharmacologic intervention and represents a promising candidate for the treatment of cognitive impairment associated with LC. This study supports the feasibility and safety of at-home MMT and provides preliminary, exploratory signals of benefit in selected cognitive domains and emotional well-being in people with LC. Future larger, adequately powered, mechanistically informed trials will be needed to confirm these findings.

1

2

3

4

5

6

7

8

9

10

11

12

13

14

15

16

17

18

19

20

21

22

23

24

25

26

27

28

29

30

31

32

33

34

35

36

37

38

39

40

41

42

43

44

45

46

47

48

49

50

51

52

53

54

55

56

57

58

59

60

Data availability

De-identified data and supporting documents will be available upon reasonable request.

10

11

12

13

14

15

16

17

18

19

20

21

22

23

24

25

26

27

28

29

30

31

32

33

34

35

36

37

38

39

40

41

42

43

44

45

46

47

48

49

50

51

52

53

54

55

56

57

58

59

60

Funding

This work was funded by Fareon, Inc.

10

11

12

13

14

15

16

17

18

19

20

21

22

23

24

25

26

27

28

29

30

31

32

33

34

35

36

37

38

39

40

41

42

43

44

45

46

47

48

49

50

51

52

53

54

55

56

57

58

59

60

Competing interests

Blake Gurfein and David Maltz are employed by Fareon, Inc. All other authors declare no competing interests.

10

11

12

13

14

15

16

17

18

19

20

21

22

23

24

25

26

27

28

29

30

31

32

33

34

35

36

37

38

39

40

41

42

43

44

45

46

47

48

49

50

51

52

53

54

55

56

57

58

59

60

References

1. Mandel H, Yoo YJ, Allen AJ, et al. Long COVID incidence proportion in adults and children between 2020 and 2024: An electronic health record-based study from the RECOVER initiative. *Clinical Infectious Diseases*. 2025;80(6):1247-1261. doi:10.1093/cid/ciaf046
2. Goldowitz I, Worku T, Brown L, Fineberg H V. *A Long COVID definition: A chronic, systemic disease state with profound consequences*. National Academies Press (US); 2024. doi:10.17226/27768
3. Ford ND, Agedew A, Dalton AF, Singleton J, Perrine CG, Saydah S. Notes from the field: Long COVID prevalence among adults — United States, 2022. *MMWR Morb Mortal Wkly Rep*. 2024;73(6):135–136. doi:https://doi.org/10.15585/mmwr.mm7306a4
4. Proal AD, VanElzakker MB, Aleman S, et al. SARS-CoV-2 reservoir in post-acute sequelae of COVID-19 (PASC). *Nat Immunol*. 2023;24(10):1616-1627. doi:10.1038/s41590-023-01601-2
5. Iwasaki A, Putrino D. Why we need a deeper understanding of the pathophysiology of Long COVID. *Lancet Infect Dis*. 2023;23(4):393-395. doi:10.1016/S1473-3099(23)00053-1

6. Davis HE, McCorkell L, Vogel JM, Topol EJ. Long COVID: Major findings, mechanisms and recommendations. *Nat Rev Microbiol.* 2023;21(3):133-146. doi:10.1038/s41579-022-00846-2
7. Cutler DM. The costs of Long COVID. *JAMA Health Forum.* 2022;3(5):e221809-e221809. doi:10.1001/jamahealthforum.2022.1809
8. Kim D. A nationwide study of risk factors for Long COVID and its economic and mental health consequences in the United States. *Communications medicine.* 2025;5(1):104. doi:10.1038/s43856-025-00759-0
9. Ceban F, Ling S, Lui LMW, et al. Fatigue and cognitive impairment in Post-COVID-19 Syndrome: A systematic review and meta-analysis. *Brain Behav Immun.* 2022;101:93-135. doi:https://doi.org/10.1016/j.bbi.2021.12.020
10. Becker JH, Lin JJ, Doernberg M, et al. Assessment of cognitive function in patients after COVID-19 infection. *JAMA Netw Open.* 2021;4(10):e2130645-e2130645. doi:10.1001/jamanetworkopen.2021.30645
11. VanElzakker MB, Bues HF, Brusafferri L, et al. Neuroinflammation in post-acute sequelae of COVID-19 (PASC) as assessed by [11C]PBR28 PET correlates with vascular disease measures. *Brain Behav Immun.* 2024;119:713-723. doi:https://doi.org/10.1016/j.bbi.2024.04.015
12. Fernández-Castañeda A, Lu P, Geraghty AC, et al. Mild respiratory COVID can cause multi-lineage neural cell and myelin dysregulation. *Cell.* 2022;185(14):2452-2468.e16. doi:10.1016/j.cell.2022.06.008
13. Stefano GB, Ptacek R, Ptackova H, Martin A, Kream RM. Selective neuronal mitochondrial targeting in SARS-CoV-2 infection affects cognitive processes to induce “brain fog” and results in behavioral changes that favor viral survival. *Med Sci Monit.* 2021;27:e930886. doi:10.12659/MSM.930886
14. Braga J, Lepira M, Kish SJ, et al. Neuroinflammation after COVID-19 with persistent depressive and cognitive symptoms. *JAMA Psychiatry.* 2023;80(8):787-795. doi:10.1001/jamapsychiatry.2023.1321
15. Visser D, Golla SS V, Verfaillie SCJ, et al. Long COVID is associated with extensive *in-vivo* neuroinflammation on [18F]DPA-714 PET. *medRxiv.* Published online January 1, 2022:2022.06.02.22275916. doi:10.1101/2022.06.02.22275916
16. Becker JH, Lin JJ, Twumasi A, et al. Greater executive dysfunction in patients post-COVID-19 compared to those not infected. *Brain Behav Immun.* 2023;114:111-117. doi:https://doi.org/10.1016/j.bbi.2023.08.014

17. Becker JH, Li J, Lin JJ, et al. Neurocognitive trajectories in Long COVID: Evidence from longitudinal analyses. *Brain Behav Immun Health*. 2025;48:101093. doi:https://doi.org/10.1016/j.bbih.2025.101093
18. Rohde CH, Taylor EM, Alonso A, Ascherman JA, Hardy KL, Pilla AA. Pulsed electromagnetic fields reduce postoperative interleukin-1 β , pain, and inflammation: A double-blind, placebo-controlled study in TRAM flap breast reconstruction patients. *Plast Reconstr Surg*. 2015;135(5).
19. Rasouli J, Lekhraj R, White NM, et al. Attenuation of interleukin-1beta by pulsed electromagnetic fields after traumatic brain injury. *Neurosci Lett*. 2012;519(1):4-8. doi:https://doi.org/10.1016/j.neulet.2012.03.089
20. Nguyen N, Brady NR, Timblin GA, Tharp KM, Gurfein BT. Transcranial microtesla magnetic fields suppress neuroinflammation and neuronal oxidative stress burden. *iScience*. 2026;29(1):114425. doi:https://doi.org/10.1016/j.isci.2025.114425
21. Petroff D, Bacak M, Dagres N, Dilk P, Wachter R. A simple blinding index for randomized controlled trials. *Contemp Clin Trials Commun*. 2024;42:101393. doi:10.1016/j.conctc.2024.101393
22. Wechsler D. *Wechsler Adult Intelligence Scale*. 4th ed. Pearson; 2008.
23. Benedict RHB, Schretlen D, Groninger L, Brandt J. Hopkins Verbal Learning Test – Revised: Normative Data and Analysis of Inter-Form and Test-Retest Reliability. *Clin Neuropsychol*. 1998;12(1):43-55. doi:10.1076/clin.12.1.43.1726
24. Delis DC, Kaplan E, Kramer JH. *Delis-Kaplan Executive Function System (D-KEFS) Examiner's Manual*. The Psychological Corporation; 2001.
25. Reitan RM. *Validity of the Trail Making Test as an Indicator of Organic Brain Damage*. Vol 8. 1958. doi:10.2466/pms.1958.8.3.271
26. Ruff RM, Allen PA. *Ruff 2 & 7 Selective Attention Test: Professional Manual*. Psychological Assessment Resources; 1996.
27. Benedict RB. *Brief Visuospatial Memory Test--Revised: Professional Manual*. Psychological Assessment Resources; 1997.
28. Meyers JE, Meyers KR. *Rey Complex Figure Test and Recognition Trial: Professional Manual*. Psychological Assessment Resources; 1995.
29. Smith A. *Symbol Digit Modalities Test (SDMT) Manual (Revised)*. Western Psychological Services; 1982.
30. Gollan TH, Weissberger GH, Runnqvist E, Montoya RI, Cera CM. Self-Ratings of spoken language dominance: A Multilingual Naming Test (MINT) and preliminary norms for

- young and aging spanish-english bilinguals. *Bilingualism: Language and Cognition*. 2012;15(3):594-615. doi:10.1017/S1366728911000338
31. Kroenke K, Spitzer RL, Williams JBW. The PHQ-9: Validity of a brief depression severity measure. *J Gen Intern Med*. 2001;16(9):606-613. doi:10.1046/j.1525-1497.2001.016009606.x
 32. Spitzer RL, Kroenke K, Williams JBW, Lowe B. A brief measure for assessing generalized anxiety disorder: The GAD-7. *Arch Intern Med*. 2006;166(10):1092-1097. doi:10.1001/archinte.166.10.1092
 33. Cotler J, Holtzman C, Dudun C, Jason LA. A brief questionnaire to assess post-exertional malaise. *Diagnostics*. 2018;8(3):66. doi:10.3390/diagnostics8030066
 34. Cella D, Riley W, Stone A, et al. The Patient-Reported Outcomes Measurement Information System (PROMIS) developed and tested its first wave of adult self-reported health outcome item banks: 2005-2008. *J Clin Epidemiol*. 2010;63(11):1179-1194. doi:10.1016/j.jclinepi.2010.04.011
 35. Ware JE, Sherbourne CD. The MOS 36-Item Short-Form Health Survey (SF-36): I. conceptual framework and item selection. *Med Care*. 1992;30(6):473-483.
 36. Muir RT, Hill MD, Black SE, Smith EE. Minimal clinically important difference in Alzheimer's disease: Rapid review. *Alzheimer's & Dementia*. 2024;20(5):3352-3363. doi:https://doi.org/10.1002/alz.13770
 37. Kounali D, Button KS, Lewis G, et al. How much change is enough? Evidence from a longitudinal study on depression in UK primary care. *Psychol Med*. 2022;52(10):1875-1882. doi:DOI: 10.1017/S0033291720003700
 38. Becker JH, Watson E, Zubair N, et al. Preliminary evaluation of a cognitive rehabilitation intervention for post-COVID-19 cognitive impairment: A pilot randomized controlled trial. *Neuropsychol Rehabil*. 2025;36(5):853-864. doi:10.1080/09602011.2025.2552154
 39. Zilberman-Itskovich S, Catalogna M, Sasson E, et al. Hyperbaric oxygen therapy improves neurocognitive functions and symptoms of post-COVID condition: randomized controlled trial. *Sci Rep*. 2022;12(1):11252. doi:10.1038/s41598-022-15565-0
 40. Knopman DS, Koltai D, Laskowitz DT, et al. Evaluation of interventions for cognitive symptoms in Long COVID: A randomized clinical trial. *JAMA Neurol*. 2026;83(1):49-59. doi:10.1001/jamaneurol.2025.4415
 41. Herrera E, Pérez-Sánchez M del C, San Miguel-Abella R, et al. Cognitive impairment in young adults with post COVID-19 syndrome. *Sci Rep*. 2023;13(1):6378. doi:10.1038/s41598-023-32939-0

42. Möller M, Borg K, Janson C, Lerm M, Normark J, Niward K. Cognitive dysfunction in post-COVID-19 condition: Mechanisms, management, and rehabilitation. *J Intern Med.* 2023;294(5):563-581. doi:10.1111/joim.13720

43. Clark P, Rosenberg P, Oh ES, et al. Methylphenidate for the treatment of post-COVID cognitive dysfunction (brain fog). *J Med Cases.* 2024;15(8):195-200. doi:10.14740/jmc4254

44. Pooladgar P, Sakhabakhsh M, Soleiman-Meigooni S, Taghva A, Nasiri M, Darazam IA. The effect of donepezil hydrochloride on post-COVID memory impairment: A randomized controlled trial. *J Clin Neurosci.* 2023;118:168-174. doi:10.1016/j.jocn.2023.09.005

45. Oliver-Mas S, Matias-Guiu JA, Delgado-Alonso C, et al. A randomized comparative feasibility study of neuromodulation and cognitive training for post-COVID fatigue. *Sci Rep.* 2025;15(1):26818. doi:10.1038/s41598-025-09772-8

46. Mischke M, Zaehle T. Modulating subjective and objective cognitive state fatigue in long COVID with repetitive anodal tDCS: results from a double-blinded randomized controlled trial. *BMC Neurosci.* 2026;27(1):6. doi:10.1186/s12868-025-00989-x

47. Linnhoff S, Haghikia A, Zaehle T. Effects of repetitive twice-weekly transcranial direct current stimulations on fatigue and fatigability in people with multiple sclerosis. *Sci Rep.* 2023;13(1):5878. doi:10.1038/s41598-023-32779-y

48. Matits L, Schellenberg J, Mack M, et al. Circulating mitochondrial and cellular damage markers in long COVID: Links to cognitive function, psychological distress, and inflammation. *Mol Psychiatry.* Published online 2026. doi:10.1038/s41380-026-03471-0

49. Szögi T, Borsos BN, Masic D, et al. Novel biomarkers of mitochondrial dysfunction in Long COVID patients. *Geroscience.* 2025;47(2):2245-2261. doi:10.1007/s11357-024-01398-4

50. Xu W tao, An X bin, Chen M jie, et al. A gene cluster of mitochondrial complexes contributes to the cognitive decline of COVID-19 infection. *Mol Neurobiol.* 2025;62(6):6869-6883. doi:10.1007/s12035-024-04471-3

Figure legends

Figure 1. Device. (A) Fareon Restore Headset positioned on head for therapy; (B) Fareon Restore Delivery System

Alt text: Photo of a person wearing the headset positioned above the forehead (A), and image of a blue device connected to a circular headset (B).

Figure 2. Study Design and Schedule of Procedures.

Alt text: Participants with objective cognitive impairment from long COVID were randomized 2:1 to active MMT or sham in a triple-blind pilot trial (n = 30 completed all procedures). Eight 15-minute sessions were self-administered twice weekly, at least 70 h apart, across a 4-week treatment period, followed by a 4-week follow-up period without treatment. Neurocognitive and self-report assessments were repeated at all three in-person visits (Weeks 0, 4, and 8), safety questionnaires were completed weekly during the treatment period, and device usability ratings and treatment allocation guesses were collected at Week 4.

Figure 3. CONSORT Flow Diagram.

Alt text: CONSORT flow diagram showing participant screening with number of exclusions and reasons, enrollment and randomization, allocation to active and sham groups with number of withdrawals and reasons, and study completion.



Device. (A) Fareon Restore Headset positioned on head for therapy; (B) Fareon Restore Delivery System
215x144mm (300 x 300 DPI)

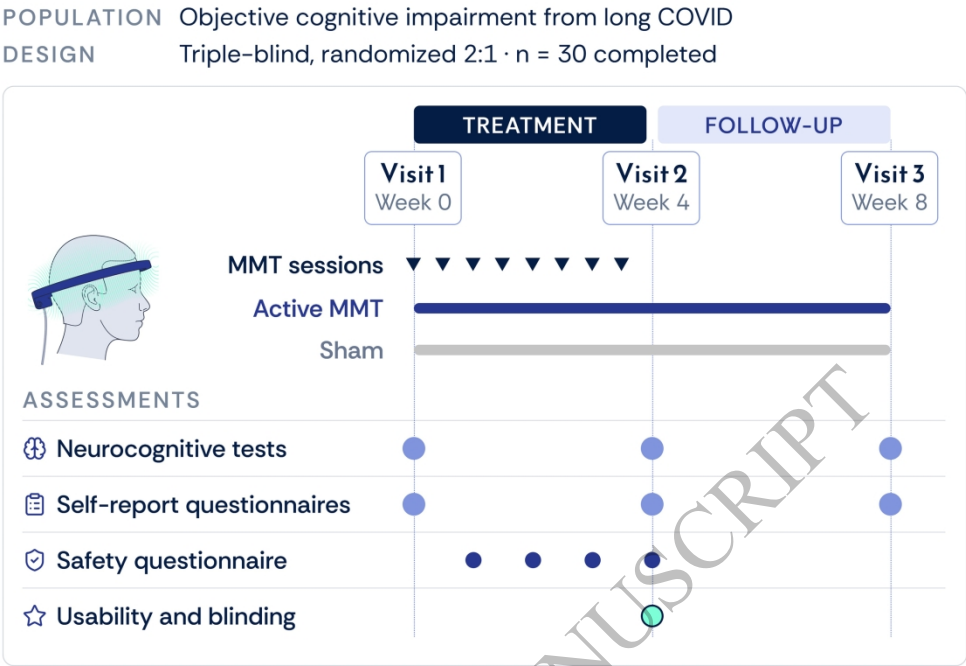


Figure 2. Study Design and Schedule of Procedures.

215x148mm (300 x 300 DPI)

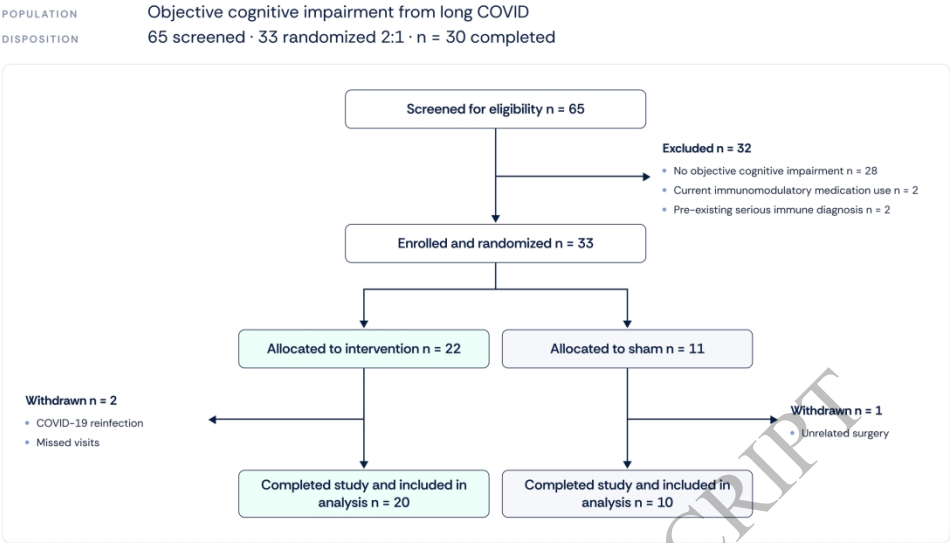


Figure 3. CONSORT Flow Diagram.
215x122mm (300 x 300 DPI)

Table 1. Outcome measures and description of domains assessed

Measure	Domains and subdomains
Neurocognitive measures	
Wechsler Adult Intelligence Scale Fourth Edition (WAIS-IV) Digit Span Forward	Basic auditory attention
WAIS-IV Digit Span Backward (DSB)	Working memory
WAIS-IV Digit Span Sequencing (DSS)	Working memory and executive attention
Hopkins Verbal Learning Test–Revised (HVLTR)	Verbal learning, delayed recall, and retention
Trail Making Test A (TMT A)	Divided attention and graphomotor speed
Trail Making Test B (TMT B)	Cognitive flexibility and executive functioning
Delis-Kaplan Executive Function System (D-KEFS) Verbal Fluency	Language, initiation/fluency, and executive control
D-KEFS Color Word Interference	Processing speed and visuomotor function
Ruff 2 & 7	Sustained and selective attention, inhibition
Brief Visuospatial Memory Test (BVMPT)	Visuospatial memory
Rey Complex Figure Test (RCFT)	Visuospatial ability
Symbol Digit Modalities Test (SDMT)	Processing speed and working memory efficiency
Multilingual Naming Test (MINT)	Language and dysnomia
Mood and quality of life measures	
Patient Health Questionnaire 9 (PHQ-9)	Presence of depressive symptoms over the past two weeks
Generalized Anxiety Disorder 7 (GAD-7)	Presence of anxiety symptoms over the past two weeks
DePaul Symptom Questionnaire Post-Exertional Malaise (DSQ-PEM)	Post-exertional malaise, including symptom exacerbation after physical or cognitive exertion, fatigue recovery time, and functional impact
PROMIS Fatigue Short Form-7a	Severity and impact of fatigue
36-Item Short Form Health Survey (SF-36)	General health-related quality of life across eight domains: physical functioning, role limitations (physical), bodily pain, general health, vitality, social functioning, role limitations (emotional), and mental health
Feasibility measures	
Device Usability Ratings	Assessment of device usability and user experience

Abbreviations: WAIS-IV, Wechsler Adult Intelligence Scale, Fourth Edition; HVLTR, Hopkins Verbal Learning Test-Revised; TMT, Trail Making Test; D-KEFS, Delis-Kaplan Executive Function System; BVMPT, Brief Visuospatial Memory Test; RCFT, Rey Complex Figure Test; SDMT, Symbol Digit Modalities Test; MINT, Multilingual Naming Test; PHQ-9, Patient Health Questionnaire-9; GAD-7, Generalized Anxiety Disorder-7; DSQ-PEM, DePaul Symptom Questionnaire-Post-Exertional Malaise; PROMIS, Patient-Reported Outcomes Measurement Information System; SF-36, 36-Item Short Form Health Survey.

Table 2. Baseline demographic and clinical characteristics of study participants

Variable	Treatment			P-value
	Sham (N = 10)	Active (N = 20)	All (N = 30)	
Age	48.5 (11.7)	47.7 (13.9)	47.9 (13.0)	0.870 t-test
Sex				0.675 Fisher's exact
Female	8 (80.0%)	13 (65.0%)	21 (70.0%)	
Male	2 (20.0%)	7 (35.0%)	9 (30.0%)	
Education (in years)	17.9 (2.7)	17.5 (2.4)	17.6 (2.5)	0.648 t-test
Race				0.011 Fisher's exact
Asian	1 (10.0%)	2 (10.0%)	3 (10.0%)	
Black	2 (20.0%)	1 (5.0%)	3 (10.0%)	
White	3 (30.0%)	16 (80.0%)	19 (63.3%)	
Other	3 (30.0%)	0 (00.0%)	3 (10.0%)	
Ethnicity				1.0 Fisher's exact
Hispanic or Latino	2 (20.0%)	3 (15.0%)	5 (16.7%)	
Non-Hispanic or Latino	8 (80.0%)	17 (85.0%)	25 (83.3%)	
Months since SARS-CoV-2 infection	38.9 (12.9)	45.6 (15.7)	43.4 (15.0)	0.513 t-test

Data are presented as mean (SD) for continuous variables and n (%) for categorical variables. P-values are from independent samples t-tests (continuous) or Fisher's exact tests (categorical). SD, standard deviation.

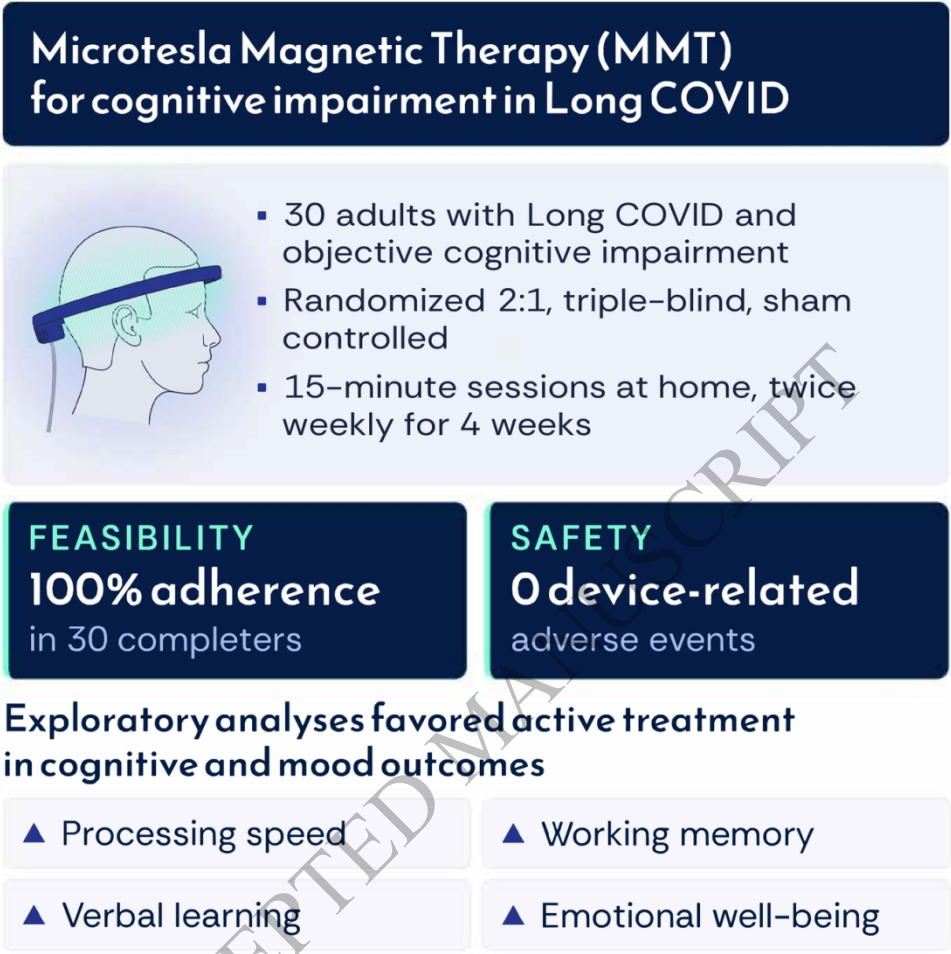
Table 3. Change from baseline in outcome measures by treatment group at Weeks 4 and 8

Outcome	Week	Sham N	Active N	Sham Mean (SD)	Active Mean (SD)	Active - Sham (95%CI)	t Ratio	DF	P-value
Digit Span Forward	4 ΔBL	10	20	1.10 (5.63)	4.30 (7.60)	3.20 (-1.9, 8.28)	1.30	23.6	0.2058
	8 ΔBL	10	20	3.20 (6.00)	3.90 (7.11)	0.70 (-4.4, 5.85)	0.28	21.2	0.7801
Digit Span Backward	4 ΔBL	10	20	3.80 (9.67)	3.00 (7.12)	-0.8 (-8.2, 6.59)	-0.23	14.0	0.8198
	8 ΔBL	10	20	2.70 (4.83)	5.65 (8.83)	2.95 (-2.2, 8.07)	1.18	27.6	0.2473
Digit Span Sequencing	4 ΔBL	10	20	-0.5 (4.14)	1.30 (7.35)	1.80 (-2.5, 6.11)	0.86	27.4	0.3992
	8 ΔBL	10	20	-2.1 (4.12)	3.30 (8.49)	5.40 (0.68, 10.1)	2.34	28.0	0.0264*
HVLT-R Total Recall	4 ΔBL	10	20	-4.1 (12.3)	1.34 (13.9)	5.47 (-4.9, 15.8)	1.10	20.4	0.2844
	8 ΔBL	10	20	-4.4 (9.31)	4.62 (13.6)	9.00 (0.28, 17.7)	2.13	25.0	0.0436*
HVLT-R Delayed Recall	4 ΔBL	9	20	1.75 (11.0)	0.18 (15.2)	-1.6 (-12, 8.83)	-0.31	21.2	0.7577
	8 ΔBL	8	20	1.25 (10.5)	1.44 (14.4)	0.20 (-10, 10.5)	0.04	17.9	0.9686
D-KEFS Color Naming	4 ΔBL	10	20	1.80 (5.67)	5.85 (14.4)	4.05 (-3.5, 11.6)	1.10	27.1	0.2820
	8 ΔBL	10	20	3.70 (5.44)	11.1 (14.1)	7.40 (0.05, 14.8)	2.06	27.0	0.0487*
D-KEFS Word Reading	4 ΔBL	10	20	3.70 (12.9)	8.45 (13.3)	4.75 (-5.8, 15.3)	0.94	18.6	0.3590
	8 ΔBL	10	20	7.90 (12.5)	9.10 (14.8)	1.20 (-9.5, 11.9)	0.23	21.1	0.8182
D-KEFS Inhibition	4 ΔBL	10	20	7.50 (9.03)	12.4 (15.1)	4.90 (-4.2, 14.0)	1.11	26.9	0.2774
	8 ΔBL	10	20	14.3 (11.5)	14.7 (16.3)	0.35 (-10, 11.0)	0.07	24.4	0.9464
D-KEFS Inhibition/Switching	4 ΔBL	10	20	9.10 (7.84)	9.90 (13.2)	0.80 (-7.1, 8.71)	0.21	27.0	0.8371
	8 ΔBL	10	20	11.5 (12.3)	12.7 (13.4)	1.15 (-9.1, 11.4)	0.23	19.6	0.8170
D-KEFS Letter Fluency	4 ΔBL	10	20	2.70 (8.06)	5.35 (7.98)	2.65 (-3.9, 9.18)	0.85	17.9	0.4054
	8 ΔBL	10	20	5.00 (6.53)	6.15 (8.71)	1.15 (-4.7, 7.02)	0.41	23.4	0.6891
D-KEFS Category Switching	4 ΔBL	10	20	1.10 (12.3)	0.95 (8.64)	-0.2 (-9.5, 9.19)	-0.03	13.6	0.9729
	8 ΔBL	10	20	3.60 (7.21)	5.10 (8.84)	1.50 (-4.8, 7.76)	0.50	21.8	0.6243
Trail A	4 ΔBL	9	20	3.11 (8.94)	6.45 (10.3)	3.34 (-4.6, 11.3)	0.88	17.8	0.3875
	8 ΔBL	9	20	5.11 (13.2)	12.5 (11.7)	7.39 (-3.6, 18.4)	1.45	13.9	0.1704
Trail B	4 ΔBL	9	20	7.11 (6.45)	6.05 (9.86)	-1.1 (-7.4, 5.31)	-0.34	23.0	0.7336
	8 ΔBL	9	20	7.11 (10.2)	8.00 (9.10)	0.89 (-7.6, 9.40)	0.22	14.0	0.8259
Ruff 2&7 Automatic Speed	4 ΔBL	10	20	2.50 (5.60)	5.70 (6.39)	3.20 (-1.5, 7.94)	1.41	20.4	0.1748

Outcome	Week	Sham N	Active N	Sham Mean (SD)	Active Mean (SD)	Active - Sham (95%CI)	t Ratio	DF	P-value
Ruff 2&7 Controlled Speed	8 ΔBL	10	20	3.90 (7.37)	9.70 (9.22)	5.80 (-0.6, 12.2)	1.86	22.2	0.0756
	4 ΔBL	10	20	3.90 (8.33)	5.75 (9.34)	1.85 (-5.2, 8.86)	0.55	20.1	0.5882
	8 ΔBL	10	20	3.40 (9.78)	9.00 (9.94)	5.60 (-2.4, 13.6)	1.47	18.4	0.1583
Ruff 2&7 Total Speed	4 ΔBL	10	20	3.00 (7.07)	5.95 (7.75)	2.95 (-3.0, 8.86)	1.04	19.7	0.3097
	8 ΔBL	10	20	3.50 (8.54)	9.45 (8.94)	5.95 (-1.1, 13.0)	1.77	18.9	0.0927
BVMT total recall	4 ΔBL	10	20	5.10 (10.1)	2.35 (14.1)	-2.8 (-12, 6.48)	-0.61	24.2	0.5446
	8 ΔBL	9	20	-1.7 (20.0)	1.50 (11.4)	3.17 (-13, 19.0)	0.44	10.4	0.6659
SDMT	4 ΔBL	10	20	-1.8 (12.8)	4.50 (9.69)	6.30 (-3.5, 16.1)	1.37	14.4	0.1908
	8 ΔBL	10	20	7.10 (6.33)	5.35 (9.57)	-1.8 (-7.8, 4.28)	-0.60	25.5	0.5556
PHQ-9	4 ΔBL	9	19	-1.1 (4.59)	-2.5 (5.53)	-1.4 (-5.5, 2.80)	-0.69	18.8	0.5017
	8 ΔBL	9	20	-2.3 (5.70)	-2.8 (5.16)	-0.4 (-5.2, 4.35)	-0.19	14.2	0.8540
GAD-7	4 ΔBL	10	20	0.20 (4.39)	-2.6 (3.10)	-2.8 (-6.1, 0.59)	-1.77	13.7	0.0988
	8 ΔBL	10	20	-0.1 (3.81)	-3.0 (3.32)	-2.9 (-5.9, 0.10)	-2.05	16.0	0.0574
DSQ-PEM	4 ΔBL	8	19	-1.5 (3.12)	-1.7 (8.69)	-0.2 (-4.9, 4.46)	-0.10	24.7	0.9180
	8 ΔBL	8	19	1.25 (8.14)	-2.3 (6.57)	-3.6 (-11, 3.58)	-1.10	11.0	0.2956
SF-36 Emotional Well-Being	4 ΔBL	10	20	0.40 (15.1)	7.60 (14.1)	7.20 (-4.9, 19.3)	1.26	17.0	0.2260
	8 ΔBL	10	20	-10 (20.3)	9.20 (11.1)	19.2 (4.15, 34.2)	2.79	11.8	0.0167*
PROMIS Fatigue	4 ΔBL	10	20	-2.7 (6.20)	-2.6 (6.11)	0.12 (-4.9, 5.14)	0.05	17.8	0.9622
	8 ΔBL	10	20	-4.6 (8.18)	-1.7 (5.70)	2.86 (-3.3, 9.06)	0.99	13.5	0.3393

Abbreviations: ΔBL, change from baseline; SD, standard deviation; CI, confidence interval; DF, degrees of freedom; HVLT-R, Hopkins Verbal Learning Test-Revised; D-KEFS, Delis-Kaplan Executive Function System; BVMT, Brief Visuospatial Memory Test; SDMT, Symbol Digit Modalities Test; PHQ-9, Patient Health Questionnaire-9; GAD-7, Generalized Anxiety Disorder-7; DSQ-PEM, DePaul Symptom Questionnaire-Post-Exertional Malaise; SF-36, 36-Item Short Form Health Survey; PROMIS, Patient-Reported Outcomes Measurement Information System.

* P < 0.05.



Graphical Abstract

119x119mm (300 x 300 DPI)