Journal of Neuroeducation
Revista de Neuroeducación - Revista de Neuroeducació

UNIVERSITAT DE BARCELONA
Edu1st
Càtedra de Neuroeducació

Neuroeducational Research

Evaluation of Li-TMS as an intervention to enhance cognitive performance in university students

Li-TMS Enhances cognitive performance

Raúl Sampieri-Cabrera[1,2]*, Alan Oviedo[3], Erandi Pérez[3]

[1]Facultad de Medicina, Universidad Nacional Autónoma de México.
[2]Centro de Ciencias de la Complejidad, Universidad Nacional Autónoma de México.
sampieri@comunidad.unam.mx; 0000-0001-7733-1105
[3]Coordinación de Investigación Nibbot International
alan@nibbot.com.mx; 0009-0000-8420-7073
investigacion@nibbot.com.mx;

*Correspondence
Raúl Sampieri Cabrera
sampieri@comunidad.unam.mx

Citation
Sampieri-Cabrera R., Oviedo A., Pérez E. Evaluation of Li-TMS as an intervention to enhance cognitive performance in university students
Li-TMS Enhances cognitive performance. JONED. Journal of Neuroeducation. 2025; 5(2): 6-13. doi: 10.1344/joned.v5i2.47351

Reception date: 22/7/2024
Acceptance date: 27/11/2024
Publication date: 15/02/2025

Author contributions
Raúl Sampieri Cabrera participated in the design of the project, design of the stimulation protocol, applied the stimulation sessions, analyzed the results and wrote the article.

Erandi Pérez and Alan Oviedo participated in the design of the project, design of the stimulation protocol, analysis of the results and writing of the article.

Sources of funding
This project was funded by Dr. Aniceto Orantes Suarez Special Chair, awarded by the Commission for University Merit of the Honorable Technical Council of the School of Medicine of UNAM.

Interest conflict
Alan Oviedo and Erandi Pérez are researchers at the company Nibbot international.

Editor
Laia Lluch Molins (Universitat de Barcelona, España)

Reviewers
Ali Nouri, Andrea Paula Goldin

Abstract

Background: Low-intensity transcranial magnetic stimulation (Li-TMS) is a non-invasive neuromodulation technique with reported effects on various pathologies. **Objective:** To evaluate the effect of Li-TMS on university students using the Digit Symbol Substitution Test (DSST). **Methods:** Thirty medical students from UNAM were selected and divided into two groups: experimental and control, participating in a randomised, single-blind controlled trial. The experimental group received Li-TMS at 25 Hz and 50% intensity for 10 days, while the control group received sham stimulation. **Results:** Sham stimulation did not produce significant changes in the control group ($p > 0.05$), whereas the experimental group showed a significant increase in post-intervention scores ($p < 0.05$). Furthermore, inter-group analysis confirmed better cognitive performance in the experimental group after the intervention ($p < 0.05$). **Conclusion:** Li-TMS is an effective tool for improving specific cognitive skills in healthy young individuals. Although these findings are promising, it is suggested to expand the sample size and employ functional neuroimaging to understand underlying mechanisms and explore educational applications.

Keywords: Li-TMS; cognitive performance; DSST; neuroscience; cognitive training.

Resum

Antecedents: La estimulació magnètica transcranial de baixa intensitat (Li-TMS) és una tècnica de neuromodulació no invasiva amb efectes reportats en diverses patologies. **Objectiu:** Avaluar l'efecte de la Li-TMS en estudiants universitaris utilitzant la prova de substitució de símbols i dígits (DSST). **Mètodes:** Es van seleccionar 30 estudiants de Medicina de la UNAM, dividits en dos grups: experimental i control, que van participar en un assaig controlat aleatoritzat i cec simple. El grup experimental va rebre Li-TMS amb 25 Hz i 50% d'intensitat durant 10 dies, mentre que el grup control va rebre una estimulació simulada. **Resultats:** L'estimulació simulada no va produir canvis significatius en el grup control ($p > 0.05$), mentre que el grup experimental va evidenciar un augment significatiu en les seves puntuacions postintervenció ($p < 0.05$). A més, l'anàlisi entre grups va confirmar un millor rendiment cognitiu en el grup experimental després de la intervenció (p < 0.05). **Conclusió:** La Li-TMS és una eina efectiva per millorar habilitats cognitives específiques en joves sans. Tot i que aquests resultats són prometedors, es suggereix ampliar les mostres i utilitzar neuroimatges funcionals per comprendre els mecanismes subjacents i explorar aplicacions.

Paraules clau: Li-TMS; rendiment cognitiu; DSST; neurociència; entrenament cognitiu.

Resumen

Antecedentes: La estimulación magnética transcraneal de baja intensidad (Li-TMS) es una técnica de neuromodulación no invasiva con efectos reportados en diversas patologías. Objetivo: Evaluar el efecto de la Li-TMS en estudiantes universitarios utilizando la prueba de sustitución de símbolos y dígitos (DSST). **Métodos:** Se seleccionaron 30 estudiantes de Medicina de la UNAM, divididos en dos grupos: experimental y control, quienes participaron en un ensayo controlado aleatorizado y ciego simple. El grupo experimental recibió Li-TMS con 25 Hz y 50% de intensidad durante 10 días, mientras que el grupo control recibió una estimulación simulada. **Resultados:** La estimulación simulada no produjo cambios significativos en el grupo control (p > 0.05), mientras que el grupo experimental evidenció un aumento significativo en sus puntuaciones post-intervención (p < 0.05). Además, el análisis entre grupos confirmó un mejor rendimiento cognitivo en el grupo experimental tras la intervención (p < 0.05). **Conclusión:** La Li-TMS es una herramienta efectiva para mejorar habilidades cognitivas específicas en jóvenes sanos. Aunque estos hallazgos son prometedores, se sugiere ampliar las muestras y emplear neuroimágenes funcionales para comprender los mecanismos subyacentes y explorar aplicaciones educativas.

Palabras clave: Li-TMS; rendimiento cognitivo; DSST; neurociencia; entrenamiento cognitivo.

Introduction

Cognitive training is based on the premise that cognitive skills such as memory, attention, and problem-solving can be improved through systematic and structured exercises[1,2]. One of the earliest studies related to cognitive training was conducted by Alfred Binet and Théodore Simon in the early 20th century, who developed the first intelligence tests[3]. Although their work did not focus directly on cognitive training, it laid the groundwork for understanding mental abilities and how they could be assessed and enhanced. In subsequent decades, researchers like Jean Piaget and Lev Vygotsky deepened the understanding of cognitive development, providing theories on how children learn and develop mental skills through interactions with their environment[4].

During the 1960s and 1970s, neuroscience began to have a significant impact on learning. Advances in brain imaging techniques allowed scientists to observe changes in the brain in response to learning and experience. Researchers like Merzenich demonstrated brain plasticity and the brain's ability to reorganise and form new neural connections in response to cognitive challenges[5]. The concept of cognitive training as a formal intervention began to emerge in the 1980s and 1990s, with interventions such as Feuerstein's "Instrumental Enrichment Programme" focusing on improving cognitive skills through structured activities designed to strengthen specific mental processes[6]. Simultaneously, the development of educational software and cognitive video games provided new tools for cognitive training, making these interventions more accessible and engaging for a broader audience[7,8]. However, studies on the effectiveness of cognitive training programs have shown mixed results; some have identified improvements in specific skills and brain plasticity, while others have not provided evidence supporting their efficacy[9-12].

Another technique with the potential to enhance cognitive training is low-intensity transcranial magnetic stimulation (Li-TMS). Li-TMS is a non-invasive technique that is effective in modulating brain activity and improving various cognitive functions. Li-TMS is used to treat several neuropsychiatric conditions, such as treatment-resistant depression and anxiety disorders. This technique involves applying repetitive magnetic pulses to the scalp to stimulate specific areas of the brain and has been proposed as a tool for improving cognitive skills in different populations[13,14].

The oscillatory effect induced by TMS enhances cognitive functions related to memory, attention, and perception[15]. Moreover, stimulation trains at specific frequencies, such as 5 Hz or individual alpha, improve cognitive tasks according to their interaction with functional oscillations[16,17]. For instance, Romei et al. (2011) demonstrated that theta and beta stimulation in the right parietal cortex produced differential effects on global and local visual processing[17]. TMS also induces synaptic plasticity similar to long-term potentiation (LTP), with effects extending beyond the stimulation period[18]. These results are promising for its application in enhancing motor skills, where pre-training motor task TMS improved performance[19]. Additionally, combining TMS with cortical coactivation during tasks amplifies Hebbian effects on skill learning[20]. The improvement in motor skill development may be associated with the effects of TMS on visual perception and participation in strategic adjustments during visual search[21,22].

In therapeutic applications, TMS is an effective tool for enhancing neuroplasticity and facilitating rehabilitation after stroke[23,24] and traumatic brain injury[25]. Additionally, it is useful in improving memory and language functions in older adults with cognitive decline[26]. TMS can also optimise human performance in complex work environments[27]. Research by Snyder (2009) has shown how the inhibition of conceptual processes by TMS can allow more direct access to sensory perception and improve specific skills such as numerosity[28]. This evidence highlights TMS's ability to modulate cognitive skills and accelerate Hebbian learning, paving the way for its application in enhancing human experiences across various domains.

Regardless of the cognitive training technique employed, the challenge remains to evaluate the effect produced by the training. Among the variety of scales used to assess cognitive performance, the Digit Symbol Substitution Test (DSST) is widely used in neuropsychology due to its brevity, reliability, and minimal influence of language, culture, or educational level. However, debate persists about which specific aspects of cognition it evaluates. This cognitive test involves associating symbols with numbers using a key displayed at the top of the page. The participant must reproduce the corresponding symbol in the spaces assigned below a series of numbers. The score is determined by the number of correct associations made within a limited time, usually 90 to 120 seconds[29,30].

This study focuses on the application of Li-TMS to university students to improve cognitive test scores. The main objective is to evaluate the effect of Li-TMS on the cognitive performance of university students.

The hypotheses to be tested in this study are as follows:

Hypothesis 1
Sham stimulation does not produce significant changes in cognitive performance measured by the DSST test before and after the intervention in the control group.

Hypothesis 2
Low-intensity transcranial magnetic stimulation (Li-TMS) significantly increases DSST scores after the intervention compared to baseline measurements in the experimental group.

Hypothesis 3
Cognitive performance measured by the DSST is significantly higher in the experimental group post-intervention compared to pre-control, post-control, and pre-experimental groups, with no significant differences between these three groups.

Materials and methods

Participants
The study included a sample of 30 university students with an average age of 20.3 ± 1.5 years. The sample was evenly divided into 15 women and 15 men. All participants signed an informed consent form before the study began.

Inclusion criteria

1. Students who voluntarily agreed to participate in the study.
2. Second-year medical students from the School of Medicine, National Autonomous University of Mexico (UNAM).
3. High-performing students with a grade point average of 9.0 or higher.

Exclusion criteria

1. Participants with a family history of epilepsy.

Elimination criteria

1. Participants who did not complete the stimulation sessions; no participants were excluded.

Study design
The study was designed as a randomised, single-blind controlled trial (only the researcher knew the treatment or intervention received by the participant). Participants were randomly assigned to two groups: an experimental group and a control group, each consisting of 15 participants. Randomisation was performed using Excel functions RANDARRAY, SORTBY, and ROWS. The experimental group received daily Li-TMS sessions (Monday to Friday) for 10 days, while the control group received low-intensity sessions following the same schedule. The stimulator used in this study was a Nibbot International device (compliant with regulations to ensure protocol accuracy).

Variable identification
Independent variable
The type of intervention was applied at two levels: low-intensity transcranial magnetic stimulation (Li-TMS) in the experimental group and a sham intervention in the control group.

Dependent variable
Cognitive performance, evaluated through scores on the Digit Symbol Substitution Test (DSST) before and after the intervention.

Controlled variables
- Duration and frequency of sessions (10 consecutive days, 45 minutes per session).
- Application area (left dorsolateral prefrontal cortex).
- Low-intensity conditions in the control group (1 Hz, 1% intensity).
- Participant selection based on inclusion and exclusion criteria (e.g., high-performing university students with not a family history of epilepsy).
- Use of the same temporal protocol for both groups.
- Evaluation using the DSST with different number keys to minimise prior learning effects.

Intervention
Recommendations for participants
Before beginning low-intensity transcranial magnetic stimulation, participants were advised not to consume alcoholic beverages, nicotine, or energy drinks for at least 5 hours before stimulation. They were also encouraged to attend sessions between 10 am and 5 pm.

Experimental group
Participants in the experimental group underwent the low-intensity transcranial magnetic stimulation (Li-TMS) protocol for 10 consecutive days. Li-TMS conditions included continuous pulses with a monophasic waveform using a circular coil applied to the left dorsolateral prefrontal cortex (DLPF-LEFT) at 50% intensity, 25 Hz frequency, and 1% pulse width. Each session lasted 45 minutes.

Control group
Participants in the control group underwent low-intensity Li-TMS sessions under the same temporal conditions as the experimental group. The intensity used was 1%, with a frequency of 1 Hz and a pulse width of 1%, applied to the DLPF-LEFT area for 45 minutes per session.

Outcome evaluation
The outcomes were assessed using the Digit Symbol Substitution Test (DSST), a widely used neuropsychological test that assesses cognitive abilities such as motor speed, attention, and visuoperceptual functions. While it does not specify the cognitive domain affected, it is useful for detecting changes in cognitive performance.

The DSST was administered on paper, requiring participants to associate symbols with numbers according to a key and reproduce as many correct symbols as possible in 60 seconds. The DSST score represented the number of correct responses.

The test was administered before (pre-group) and after the 10-day intervention period (post-group) to evaluate changes in participants' cognitive performance. Different numerical codes were used before and after the intervention to minimise prior learning effects.

Statistical analysis
Data were analysed using GraphPad Prism version 5.0. Normality was initially verified using the Shapiro-Wilk test. As the data did not follow a normal distribution, the Wilcoxon test was used to compare related samples (pre and post) within each group (experimental and control). Statistical significance was set at $p<0.05$.

To evaluate differences between groups (C-pre, C-post, E-pre, E-post), the Friedman Test was used (due to the lack of normal distribution). Post hoc comparisons were performed to identify pairs of groups differed significantly, using the Bonferroni correction for multiple comparisons. Statistical significance was established at $P < 0.05$.

Results

Sham stimulation had no effect on participants' cognitive performance.

In the control group, no significant differences were observed between pre- and post-intervention DSST scores ($p > 0.05$, Wilcoxon test). These scores remained relatively constant.

Low-intensity transcranial magnetic stimulation (Li-TMS) improved cognitive performance in the experimental group.

In the experimental group, a significant increase was observed in post-intervention scores compared to pre-intervention measurements ($p < 0.05$, Wilcoxon test).

Low-intensity transcranial magnetic stimulation (Li-TMS) improved cognitive performance in the experimental group compared with the control group.

The grouped scores of both groups (control and experimental) revealed that post-intervention cognitive performance in the experimental group was significantly higher compared to the other groups: control pre, control post, and experimental pre ($p < 0.05$, Friedman test with Bonferroni post hoc correction). No significant differences were found between these three latter groups ($p > 0.05$) (see **figure 1**).

Discussion

The results of this study demonstrate that low-intensity transcranial magnetic stimulation (Li-TMS) is effective in improving cognitive performance in university students, specifically in tasks assessed by the DSST test. This improvement, which was only observed in the experimental group after the intervention, reinforces the notion that Li-TMS can act as an effective modulator of neural networks associated with attention, processing speed, and executive functions. In contrast, the control group showed no significant differences, highlighting the specificity of the stimulation effects compared to potential changes due to external factors or prior learning.

There is evidence that cognitive interventions, such as specific video games, can induce improvements in cognitive and non-cognitive skills[32]. However, these strategies have faced criticism due to inconsistent results and challenges in the far transfer of acquired skills[33, 34]. In contrast, TMS has demonstrated the ability to induce synaptic plasticity and modulate cortical dynamics in a focal manner, allowing for a more robust and direct impact on cognitive functions[35, 40, 41].

Our findings align with research documenting the beneficial effects of Li-TMS in populations with cognitive impairment, such as patients with traumatic brain injury, Alzheimer's disease, and mild cognitive impairment[36-39]. While these studies have predominantly explored clinical applications, our findings extend these applications by demonstrating that Li-TMS can also be effective in healthy individuals, paving the way for its use as a preventive or cognitive optimisation tool in educational settings.

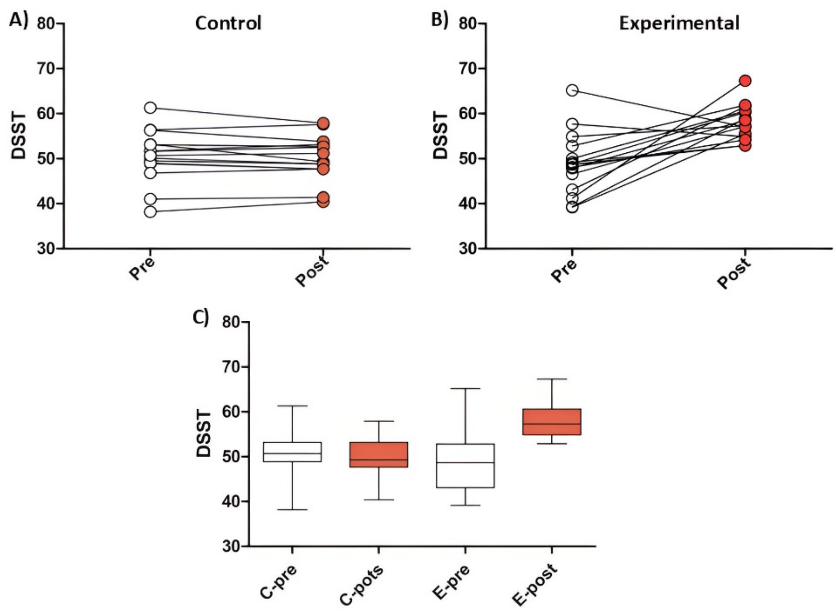

Figure 1. Effect of low-intensity transcranial magnetic stimulation (Li-TMS) on cognitive performance measured by the DSST test. A) Pre- and post-scores in the control group ($p > 0.05$, Wilcoxon test). B) Pre- and post-scores in the experimental group ($p < 0.05$, Wilcoxon test). C) Comparison of scores between the control groups (C-pre, C-post) and experimental groups (E-pre, E-post), with a significant difference in the experimental post-intervention group compared to all other groups ($p < 0.05$, Friedman test with Bonferroni post hoc correction).

A distinctive feature of this study is the improvement observed in the experimental group post-intervention, which was significantly superior not only compared to the control group but also to their own pre-intervention assessment. This suggests that the stimulation frequency (25 Hz) and location (left dorsolateral prefrontal cortex) may have facilitated the activation of neural networks associated with executive function[31]. The choice of the DSST as the assessment measure proved suitable for capturing changes in visuospatial skills and processing speed, given its low cultural and educational bias.

However, although the results are encouraging, future studies should expand the sample to include more diverse populations and adopt multidimensional cognitive batteries to explore far transfer effects and the sustainability of improvements. Additionally, this study did not include functional or molecular assessments to propose a mechanism of action for Li-TMS, underscoring the need to incorporate functional neuroimaging tools to identify correlations between observed changes and brain activity induced by Li-TMS.

Conclusions

This study highlights the potential of Li-TMS as an innovative tool to enhance specific cognitive skills beyond clinical settings. Li-TMS offers opportunities to optimise cognitive performance in young and healthy populations, which could have a positive impact on learning processes.

Limitations

1. The sample size of this study was relatively small.
2. Only the DSST was used to measure cognitive performance.
3. The study population was made up of students with grades above 9.0 (considered high academic performance), so it is necessary to include students with different academic backgrounds to evaluate whether the effect is consistent and generalizable.
4. Li-TMS is an expensive technique.

Ethical statement

This project was approved by the Ethics Committees of the School of Medicine of the National Autonomous University of Mexico (registration number FMED/CIE/AECR/150/2024).

Acknowledgments

The author thanks Armando Muñoz and Mireya Velásquez for providing technical support during the project development.

References

1. Mewborn C, Lindbergh CA, Miller LS. Cognitive interventions for enhancing executive function in older adults: A systematic review and meta-analysis of recent studies. Psychol Aging. 2017 Mar;32(1):16-28. doi: 10.1037/pag0000148.
2. Shute VJ, Ventura M, Ke F. The power of play: The effects of Portal 2 and Lumosity on cognitive and noncognitive skills. Comput Educ. 2015;80:58-67. doi: 10.1016/j.compedu.2014.08.013.
3. Binet A, Simon T. The development of intelligence in children. L'Année Psychologique. 1905;12:191-244.
4. Bjorklund DF, Causey KB. Children's Thinking: Cognitive Development and Individual Differences. 6th ed. SAGE Publications; 2018.
5. Merzenich MM, Kaas JH, Sur M. Progression of change following median nerve section in the cortical representation of the hand in areas 3b and 1 in adult owl and squirrel monkeys. Neuroscience. 1983;10(3):639-665. doi: 10.1016/0306-4522(83)90249-2.
6. Feuerstein R, Feuerstein RS, Falik LH. The Feuerstein Instrumental Enrichment Program. Educ Psychol Rev. 2010;22(1):89-101. doi: 10.1007/s10648-010-9138-7.
7. Kurzban R, Duckworth A, Kable JW, Myers J. An opportunity cost model of subjective effort and task performance. Behav Brain Sci. 2013;36(6):661-679. doi: 10.1017/S0140525X12003196.
8. Owen AM, Hampshire A, Grahn JA, Stenton R, Dajani S, Burns AS, et al. Putting brain training to the test: A randomized, controlled trial of cognitive training. Nature. 2010;465(7299):775-778. doi: 10.1038/nature09042.
9. Lampit A, Hallock H, Valenzuela M. Computerized cognitive training in cognitively healthy older adults: A systematic review and meta-analysis of effect modifiers. PLoS Med. 2014;11(11). doi: 10.1371/journal.pmed.1001756.
10. Melby-Lervåg M, Redick TS, Hulme C. Working memory training does not improve performance on measures of intelligence or other measures of "far transfer": Evidence from a meta-analytic review. Perspect Psychol Sci. 2016;11(4):512-534. doi: 10.1177/1745691616635612.
11. Morrison AB, Chein JM. Does working memory training work? The promise and challenges of enhancing cognition by training working memory. Psychon Bull Rev. 2011;18(1):46-60. doi: 10.3758/s13423-010-0034-0.
12. Sprague BN, Freed SA, Webb CE, Phillips CB, Hyun J, Ross LA. The impact of behavioral interventions on cognitive function in healthy older adults: A systematic review. Ageing Research Reviews. 2019 Jul;52:32-52. doi: 10.1016/j.arr.2019.04.002
13. Basak C, Qin S, O'Connell MA. Differential effects of cognitive training modules in healthy aging and mild cognitive impairment: A comprehensive meta-analysis of randomized controlled trials. Psychol Aging. 2020 Mar;35(2):220-249. doi: 10.1037/pag0000442.
14. Lefaucheur JP, Aleman A, Baeken C, Benninger DH, Brunelin J, Di Lazzaro V, et al. Evidence-based guidelines on the therapeutic use of repetitive transcranial magnetic stimulation (rTMS): An update (2014-2018). Clin Neurophysiol. 2020 Feb;131(2):474-528. doi: 10.1016/j.clinph.2019.11.002. Epub 2020 Jan 1. Erratum in: Clin Neurophysiol. 2020 May;131(5):1168-1169. doi: 10.1016/j.clinph.2020.02.003.
15. Buzsáki G, Draguhn A. Neuronal oscillations in cortical networks. Science. 2004 Jun 25;304(5679):1926-9. doi: 10.1126/science.
16. Klimesch W, Sauseng P, Gerloff C. Enhancing cognitive performance with repetitive transcranial magnetic stimulation at human individual alpha frequency. Eur J Neurosci. 2003 Apr;17(6):1129–1133. doi: 10.1046/j.1460-9568.2003.02517.x.
17. Romei V, Driver J, Schyns PG, Thut G. Rhythmic TMS over parietal cortex links distinct brain frequencies to global versus local visual processing. Curr Biol. 2011 Feb;21(5):334–337. doi: 10.1016/j.cub.2011.01.035.
18. Tegenthoff M, Ragert P, Pleger B, Schwenkreis P, Förster AF, Dinse HR. Improvement of tactile discrimination performance and enlargement of cortical somatosensory maps after 5 Hz rTMS. PLoS Biol. 2005 Nov;3(11):e362. doi: 10.1371/journal.pbio.0030362.
19. Boyd LA, Linsdell MA. Excitatory repetitive transcranial magnetic stimulation to left dorsal premotor cortex enhances motor consolidation of new skills. BMC Neurosci. 2009 Jul;10(72):1471–2202. doi: 10.1186/1471-2202-10-72.
20. Bütefisch CM, Khurana V, Kopylev L, Cohen LG. Enhancing encoding of a motor memory in the primary motor cortex by cortical stimulation. J Neurophysiol. 2004 May;91(5):2110–2116. doi: 10.1152/jn.01038.2003.
21. Tadin D, Silvanto J, Pascual-Leone A, Battelli L. Improved motion perception and impaired spatial suppression following disruption of cortical area MT/V5. J Neurosci. 2011 Jan;31(4):1279–1283. doi: 10.1523/JNEUROSCI.4121-10.2011.
22. Oliveri M, Zhaoping L, Mangano GR, Turriziani P, Smirni D, Cipolotti L. Facilitation of bottom-up feature detection following rTMS-interference of the right parietal cortex. Neuropsychologia. 2010 Mar;48(4):1003–1010. doi: 10.1016/j.neuropsychologia.2009.11.020.
23. Bashir S, Mizrahi I, Weaver K, Fregni F, Pascual-Leone A. Assessment and modulation of neural plasticity in rehabilitation

with transcranial magnetic stimulation. PM R. 2010 Apr;2(-Suppl. 2):S253–S268. doi: 10.1016/j.pmrj.2010.03.021.
24. Emara TH, Moustafa RR, Elnahas NM, Roushdy TM, Elganzoury AM, AboulEzz HS, Hashem HM. Repetitive transcranial magnetic stimulation at 1 Hz and 5 Hz produces sustained improvement in motor function and disability after ischaemic stroke. Eur J Neurol. 2010 Aug;17(9):1203–1209. doi: 10.1111/j.1468-1331.2010.03000.x.
25. Cicerone K, Levin H, Malec J, Stuss D, Whyte J. Cognitive rehabilitation interventions for executive function: moving from bench to bedside in patients with traumatic brain injury. J Cogn Neurosci. 2006 Jul;18(7):1212–1222. doi: 10.1162/jocn.2006.18.7.1212.
26. Solé-Padullés C, Bartrés-Faz D, Junqué C, Clemente IC, Molinuevo JL, Bargalló N, Bosch B, Sánchez-Valle R, Bernabeu M, Moral P. Repetitive transcranial magnetic stimulation effects on brain function and cognition among elders with memory dysfunction: A randomized sham-controlled study. Cereb Cortex. 2006 Oct;16(10):1487–1493. doi: 10.1093/cercor/bhj083.
27. McKinley RA, Bridges N, Walters CM, Nelson J. Modulating the brain at work using noninvasive transcranial stimulation. Neuroimage. 2012 Jan;59(1):129–137. doi: 10.1016/j.neuroimage.2011.07.075.
28. Snyder AW. Explaining and inducing savant skills: privileged access to lower level, less-processed information. Philos Trans R Soc Lond B Biol Sci. 2009 Jun;364(1522):1399–1405. doi: 10.1098/rstb.2008.0290.
29. Boake C. From the Binet-Simon to the Wechsler-Bellevue: tracing the history of intelligence testing. J Clin Exp Neuropsychol. 2002;24(3):383–405. doi: 10.1076/jcen.24.3.383.981.
30. Wechsler D. The Measurement of Adult Intelligence. Baltimore, MD: The Williams & Wilkins Company; 1939.
31. Mewborn CM, Lindbergh CA, Stephen Miller L. Cognitive Interventions for Cognitively Healthy, Mildly Impaired, and Mixed Samples of Older Adults: A Systematic Review and Meta-Analysis of Randomized-Controlled Trials. Neuropsychol Rev. 2017 Dec;27(4):403-439. doi: 10.1007/s11065-017-9350-8.
32. Shute VJ, Ventura M, Ke F. The power of play: The effects of Portal 2 and Lumosity on cognitive and noncognitive skills. Comput Educ. 2015;80:58-67. doi: 10.1016/j.compedu.2014.08.013.
33. Owen AM, Hampshire A, Grahn JA, Stenton R, Dajani S, Burns AS, et al. Putting brain training to the test: A randomized controlled trial of cognitive training. Nature. 2010;465(7299):775-778. doi: 10.1038/nature09042
34. Melby-Lervåg M, Redick TS, Hulme C. Working memory training does not improve performance on measures of intelligence or other measures of “far transfer”: Evidence from a meta-analytic review. Perspect Psychol Sci. 2016;11(4):512-534. doi: 10.1177/1745691616635612.
35. Morrison AB, Chein JM. Does working memory training work? The promise and challenges of enhancing cognition by training working memory. Psychon Bull Rev. 2011;18(1):46-60. doi: 10.3758/s13423-010-0034-0.
36. Zhou L, Huang X, Li H, Guo R, Wang J, Zhang Y, Lu Z. Rehabilitation effect of rTMS combined with cognitive training on cognitive impairment after traumatic brain injury. Am J Transl Res. 2021 Oct 15;13(10):11711-11717. PMCID: PMC8581933.
37. Bagattini C, Zanni M, Barocco F, Caffarra P, Brignani D, Miniussi C, et al. Enhancing cognitive training effects in Alzheimer’s disease: rTMS as an add-on treatment. Brain Stimul. 2020 Nov-Dec;13(6):1655-1664. doi: 10.1016/j.brs.2020.09.010.
38. Jiang L, Cui H, Zhang C, Cao X, Gu N, Zhu Y, et al. Repetitive Transcranial Magnetic Stimulation for Improving Cognitive Function in Patients With Mild Cognitive Impairment: A Systematic Review. Front Aging Neurosci. 2021 Jan 14;12:593000. doi: 10.3389/fnagi.2020.593000.
39. Beynel L, Appelbaum LG, Luber B, Crowell CA, Hilbig SA, Lim W, et al. Effects of online repetitive transcranial magnetic stimulation (rTMS) on cognitive processing: A meta-analysis and recommendations for future studies. Neurosci Biobehav Rev. 2019 Dec;107:47-58. doi: 10.1016/j.neubiorev.2019.08.018.
40. Xie Y, Li Y, Nie L, Zhang W, Ke Z, Ku Y. Cognitive Enhancement of Repetitive Transcranial Magnetic Stimulation in Patients With Mild Cognitive Impairment and Early Alzheimer’s Disease: A Systematic Review and Meta-Analysis. Front Cell Dev Biol. 2021 Sep 10;9:734046. doi: 10.3389/fcell.2021.734046.
41. Antonenko D, Fromm AE, Thams F, Grittner U, Meinzer M, Flöel A. Microstructural and functional plasticity following repeated brain stimulation during cognitive training in older adults. Nat Commun. 2023 Jun 2;14(1):3184. doi: 10.1038/s41467-023-38910-x.