Developments In Neurotechnology: Clinical Applications and Implications of Non-Invasive Neurostimulation Techniques in Neurorehabilitation

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BACKGROUND

Motor impairment is one of the most disabling consequences of stroke and focal brain injury, often resulting from damage to the primary motor cortex and its descending pathways. Recovery relies on neuroplasticity, the brain's inherent ability to reorganize and form new synaptic connections, but this process is insufficient to restore motor functions fully. To enhance recovery, non-invasive neurostimulation techniques are explored as adjuncts to therapy rather than as stand-alone treatments. Leading methods include transcranial direct current stimulation (**tDCS**), which delivers a low-intensity electrical current to modulate cortical excitability, and transcranial magnetic stimulation (**TMS**), which utilizes a magnetic coil placed over the scalp to induce or inhibit activity in specific parts of the brain. By deliberately shaping post- injury requirements of motor networks, these approaches aim to improve movement recovery in stroke and brain-injured patients, refining the design of more effective rehabilitation protocols.

OBJECTIVE

The goal of our research is to evaluate how non-invasive neurostimulation techniques modulate neuroplasticity mechanisms to enhance motor recovery after neurological injury. We focused on:

- The extent of tDCS and TMS techniques on improved motor outcomes.
- The limitations and gaps in the literature affecting current clinical applications of tDCS and TMS in rehabilitation

METHODS

Keywordsused in Web of Science search:

1.**TMS, 2. tDCS, 3. Neurohabilitation, 4. Motor Control**

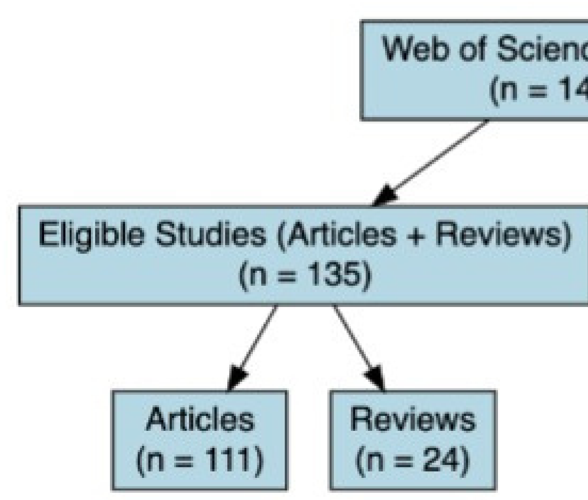

Figure 1. *WoS Method Figure*

Database Selection: After collaboratively defining our research question, we used **Web of Science (WoS)** to identify publications containing key terms such as *neurorehabilitation, neuroplasticity, motor control, and non-invasive neurostimulation techniques (tDCS, TMS).* From these results, we curated a set of the top-most-cited articles, which we then sorted to make a list of around 100 most-cited articles on non-invasive neurostimulation **[1].**

Data Analysis: Citation information from the 100 articles was organized in **Excel** or **Google Sheets,** where each intern extracted data related to publication year, journal, institution, and author contributions. Articles were Then individually read and analyzed to gain a deeper understanding of the results and neurohabilitation devices that our question refers to.

Visualization: Using the analysis from above, we created visualizations to better grasp trends, keywords **[2]**, and gaps in the literature. Common trends included increased cortical excitability, enhanced functional connectivity, and greater motor improvement, especially when Neurostimulation was paired with task-based rehabilitation.

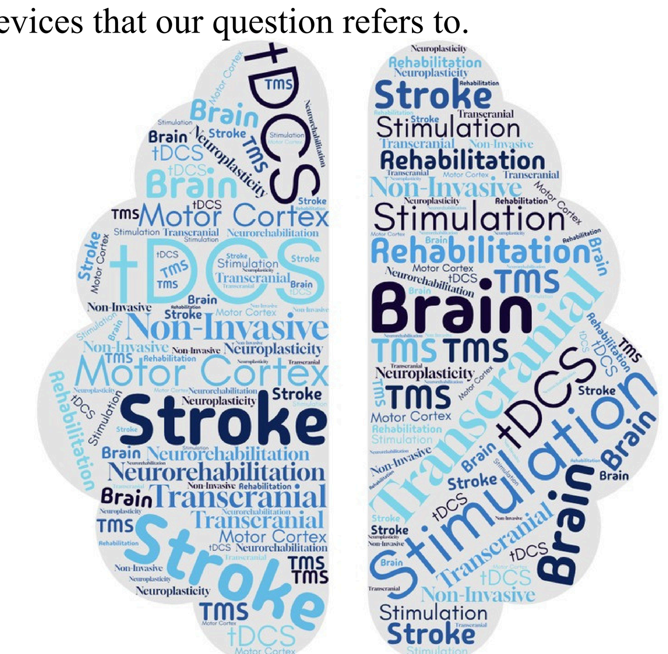

Figure 2. *Commonly Repeated Keywords*

RESULTS

Our research indicates that non-invasive neurostimulation techniques, such as tDCS and TMS, play a significant role in enhancing recovery after neurological injuries, especially stroke. These methods enhance motor function by modulating neuroplasticity, enabling the brain to reorganize and form new connections, thereby restoring previously lost capabilities. Specifically, **anodal tDCS** increases motor cortex excitability, influences intracortical inhibition, and activates both the primary cortex and associated motor areas, facilitating the rewiring of motor pathways. Targeted, high-definition tDCS further optimizes recovery by individualizing electrode placement to stimulate damaged regions effectively, supporting the reorganization of brain networks.

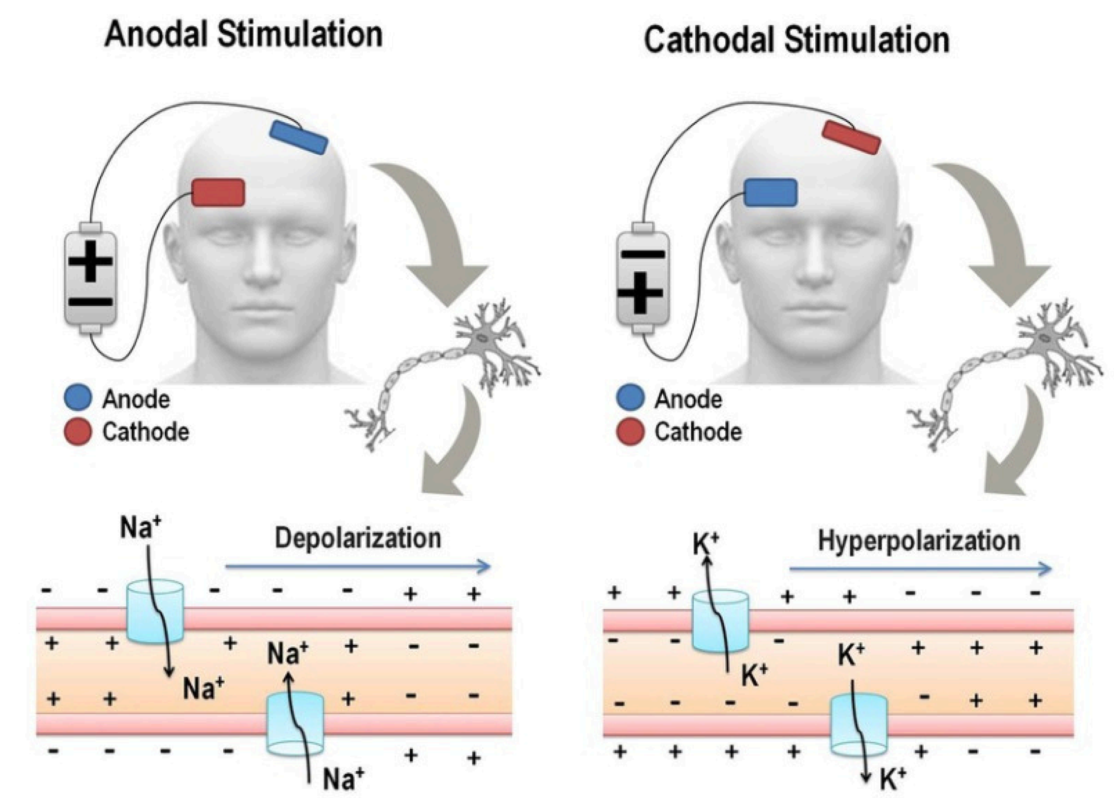

Figure 3. *Effects of anodal and cathodal stimulation on membrane polarization.*

Anodal stimulation increases neuronal excitability, depolarizing **[5]** resting membrane potentials and making neurons more likely to fire **[4]**. This can enhance motor recovery and stimulate natural learning patterns. **Cathodal** stimulation performs the opposite; it decreases neuronal excitability, hyperpolarizing **[3]** neurons and decreasing their likelihood of firing **[4]**. This helps suppress overactive brain regions. In neurorehabilitation, both anodal tDCS and cathodal tDCS are placed over the target brain region to boost excitability in damaged or underactive areas of the brain while balancing network activity. By doing this, these tools restore interhemispheric balance while promoting motor learning and recovery when paired with rehabilitation exercises.

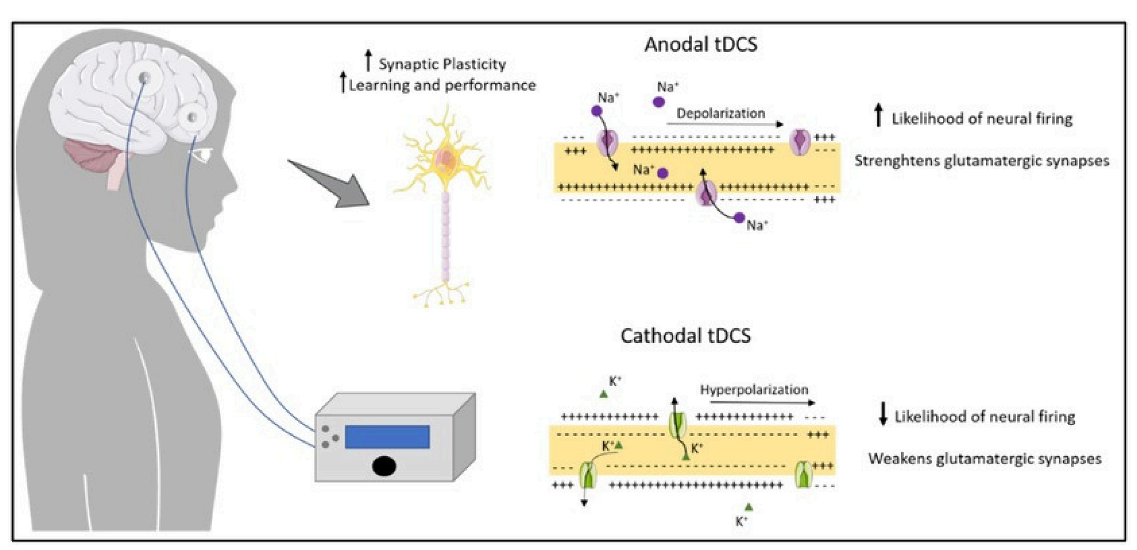

Figure 4. *Effects of anodal and cathodal tDCS*

Similarly, TMS and tDCS have been shown to promote language recovery in patients with post-stroke aphasia by engaging neuroplastic mechanisms, enabling undamaged brain areas to compensate for lost functions. These techniques exert ongoing effects during therapy, allowing them to synergize with physical or language rehabilitation to enhance learning and recovery. Overall, tDCS and TMS facilitate the restoration of neural connections, supporting both motor and language rehabilitation, and highlight their potential as effective neurorehabilitation tools for post-stroke recovery.

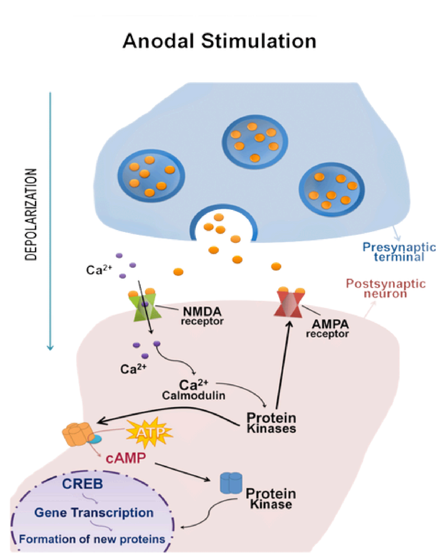

Figure 5. *Long-term Potentiation induced by anodal tDCS*

Literature Analysis:

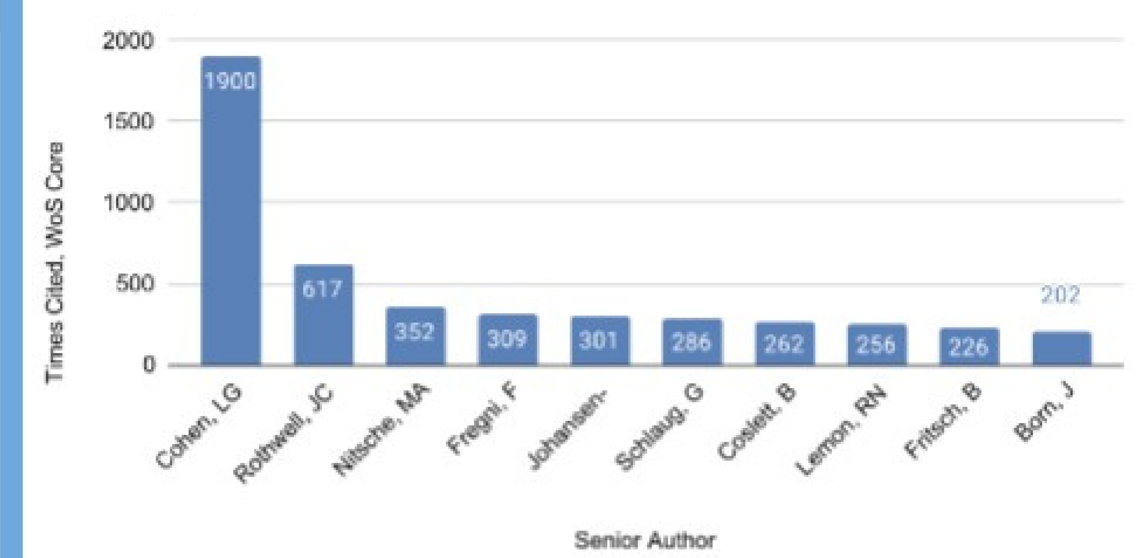

Figure 6. *Senior Authors With Multiple Top Cited Papers*

The distribution of contributing senior authors is highly disproportionate, with *Cohen, LG* standing out by a large margin. This indicates that this field is highly concentrated with few researchers driving foundational literature.

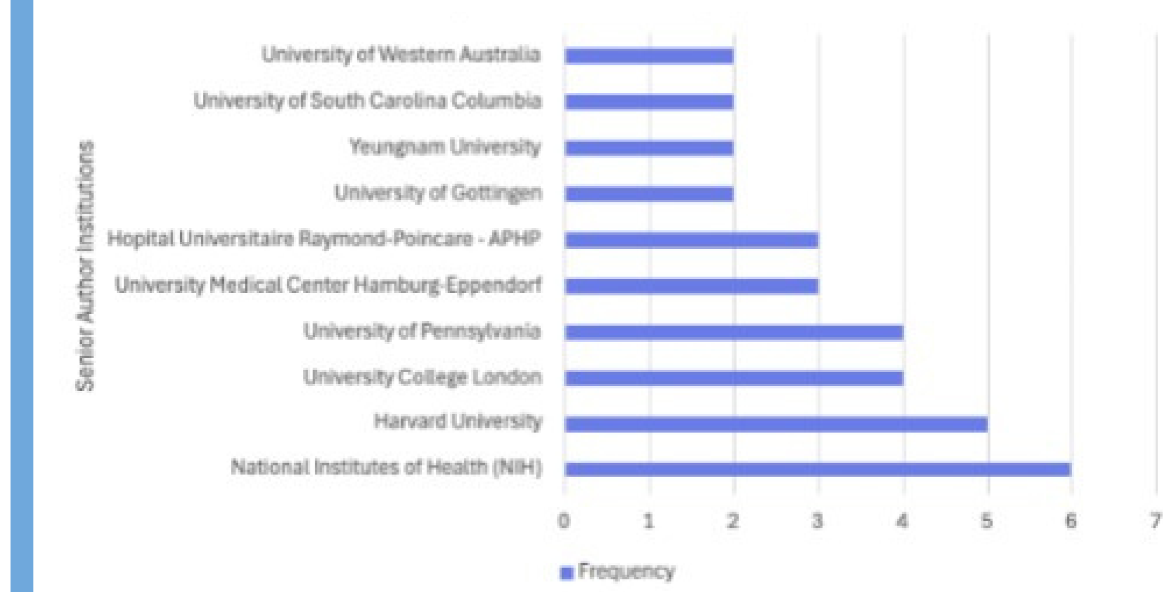

Figure 7. *Senior Author Institutions with Multiple Top Cited Papers*

Harvard University and the *National Institute of Health* appear most frequently, indicating their strong presence in non-invasive neurostimulation research. The data above support the conclusion that the majority of research is conducted by highly reputable, elite institutions.

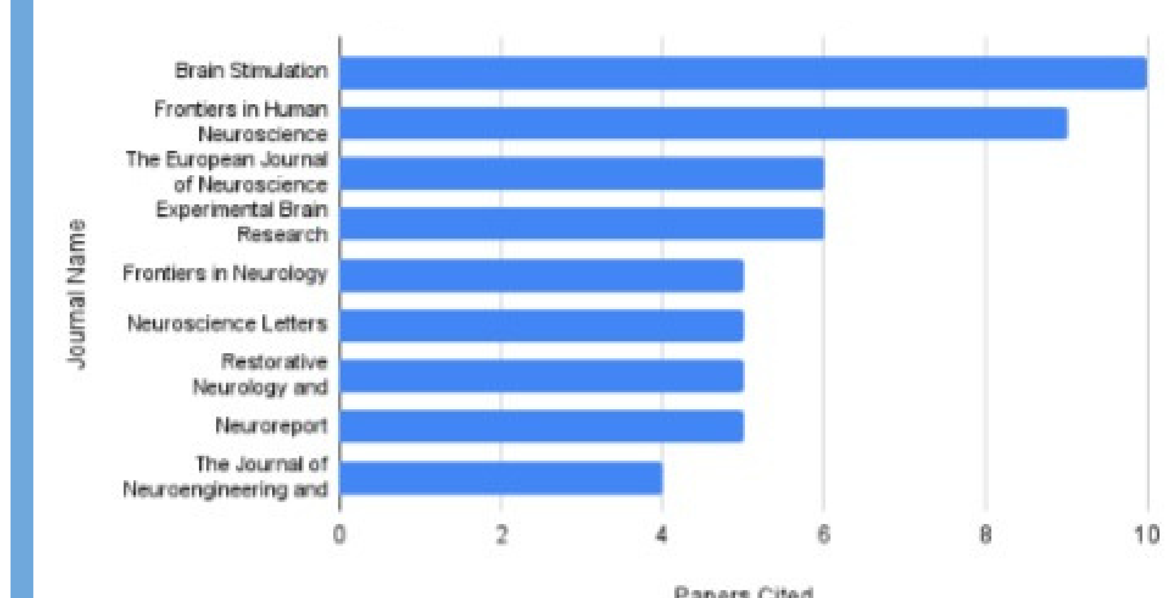

Figure 8. *Journals with Multiple Top Cited Papers*

Analysis of the journals with multiple top-cited papers shows that tDCS research is clustered within specialized neuroscience outlets, further extending the idea that the most influential work derives from domain-focused publication venues.

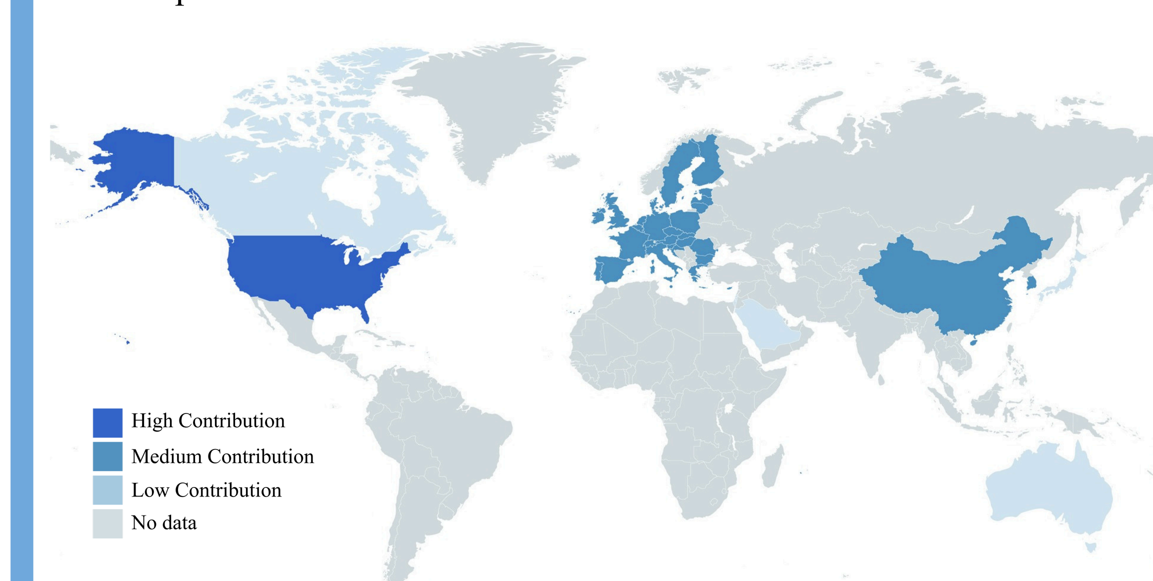

Figure 9. *Geographic Distribution of High-Impact Research*

DISCUSSION

Non-invasive neurostimulation techniques such as tDCS and TMS enhance motor recovery after neurological injuries by increasing motor cortex excitability **[3,4,5]** and modulating neuroplasticity mechanisms, improving the brain's ability to recover. Through both anodal and cathodal stimulation, these tools can either facilitate underactive regions or inhibit overactive areas, promoting the reorganization of neural networks **[4]**. This targeted modulation supports the restoration of previously lost motor functions, especially when combined with task-specific rehabilitation. Collectively, tDCS and TMS leverage the brain's inherent plasticity to optimize motor learning and functional recovery in post-injury patients.

Literature analyses indicate that research on non-invasive neurostimulation is highly concentrated within certain elite institutions, authors, and geographic regions **[6,7,8,9]**. This leaves gaps in the diverse study of populations, making it difficult to obtain consistent findings. Many of these studies included small sample sizes and large variations in protocols. Additionally, the majority of these results were paired with physical therapy or motor training, increasing the cloudiness of the isolated effects of tDCS and TMS. These limitations highlight the need for more streamlined research to fully investigate the effects of these techniques on motor recovery.

CONCLUSION

To sum up the above, our findings show that non-invasive neurostimulation techniques such as tDCS and TMS reliably enhance neuroplasticity and support improved motor outcomes following neurological injury, highlighting their promise as evidence-based adjuncts to rehabilitation **[10].** Furthermore, these tools remain safe and ethical due to their non-invasive strategy. However, differences in study design, stimulation parameters, and patient responses indicate that further standardized, large-scale research is needed before these methods can be fully optimized and widely integrated into clinical practice.

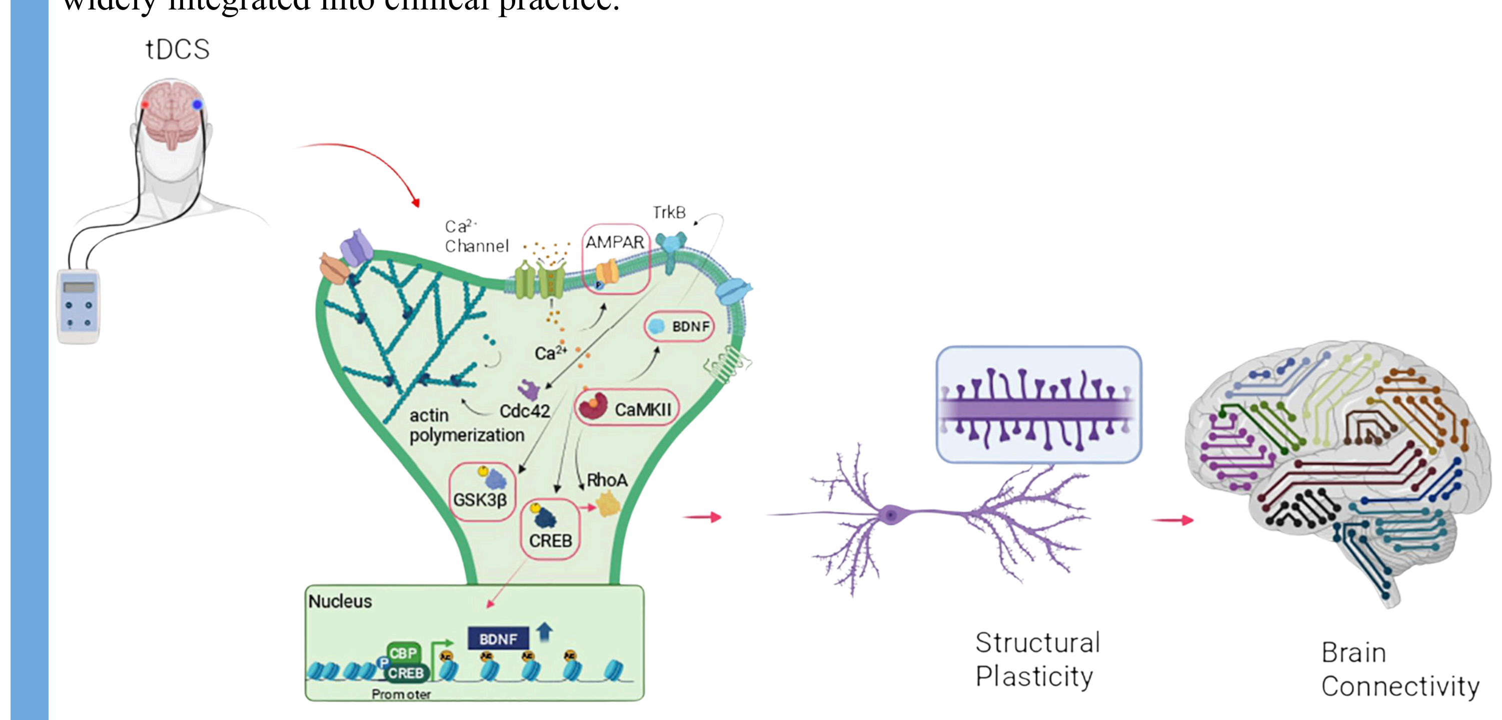

Figure 10. *Schematic representation of the molecular cascade at the basis of structural plasticity and its possible recruitment by tDCS.*

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[Database Citations] Figures created in WordClouds.com, Canva.com, Mapchart.net, RStudio's Biblioshiny, Google Sheets, and Microsoft Excel.

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