Title: Rapid Remediation of Consolidated Motor Errors via Cerebello-Cortical Beta-tACS and Variable Velocity Training: A Self-Controlled Case Study

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Abstract
The correction of consolidated, erroneous motor patterns represents a significant challenge in neurorehabilitation and sports science. Standard pedagogical approaches often fail to overwrite established procedural memories ("habits"). This single-subject case study investigates the efficacy of a novel combinatorial protocol integrating transcranial Alternating Current Stimulation (tACS) with variable velocity training. The subject presented a consolidated technical error in a complex motor task (Tennis/Rhythm Gaming) resistant to correction for six months under standard training. A specific tACS montage targeting the Cerebello-Thalamo-Cortical loop (C3-Cb2) was applied at 20 Hz (Beta frequency) during "Time Warp" training (50-80% execution speed). Following the intervention, the subject achieved full correction and consolidation of the new motor pattern within 7 days. These findings suggest that synchronizing M1-Cerebellar activity via Beta-tACS may unlock a plasticity window necessary for unlearning consolidated errors.

1. INTRODUCTION

Motor learning involves the acquisition of new muscle synergies, but motor unlearning—the suppression of a consolidated, erroneous habit—requires distinct neural mechanisms. Once a motor skill is consolidated in the basal ganglia and cerebellum, it becomes resistant to interference. This phenomenon, known as "procedural rigidification," is a major obstacle for athletes and patients.

Current literature suggests that the cerebellum plays a crucial role in error processing and sensory prediction. Furthermore, Beta oscillations (13-30 Hz) in the Primary Motor Cortex (M1) are associated with maintaining the "status quo" and controlled movement, as opposed to automaticity.

This study proposes a protocol combining:

Cerebello-Cortical tACS: To modulate the neural communication between the error-correction center (Cerebellum) and the motor command center (M1).

Variable Velocity Training ("Time Warp"): Reducing execution speed to bypass the automatic firing of the erroneous circuit, allowing the stimulated cortex to encode a new pattern.

2. METHODS

2.1 Subject

The participant is a male (Alessandro Lioy) with over 10 years of experience in tennis and rhythm gaming. The subject presented a specific, ingrained motor error (wrist execution timing) that had persisted despite 6 months of intensive standard training.

2.2 Stimulation Protocol (tACS)

Transcranial Alternating Current Stimulation was delivered using a standard stimulator.

Montage: Cerebello-Cortical setup.

Anode (Active): Over the left Primary Motor Cortex (C3, 10-20 system).

Cathode (Return): Over the right Cerebellum (Cb2, 3 cm lateral to the Inion and 1 cm below the inion-mastoid line).

Parameters: Frequency 20 Hz (Beta band); Intensity [Inserire Intensità, es. 1.5 mA]; Duration: 20 minutes per session.

2.3 Behavioral Task: The "Time Warp" Protocol

The training consisted of performing the complex motor task (osu! Catch the Beat patterns / Tennis Shadow Swings) under stimulation.

Phase A (Mapping): Execution at 50% speed. Focus on conscious proprioception.

Phase B (Consolidation): Progressive increase to 80% speed.

Phase C (Overspeed): Brief bursts at 110% speed (post-stimulation) to test stability.

Visualisation (Motor Imagery) was performed concurrently with tACS.

3. RESULTS

3.1 Acquisition Rate

Prior to the intervention, the error rate at 100% speed was constant (failed attempts > 90%) over a 6-month baseline period.

Following the introduction of the tACS + Time Warp protocol:

Day 1: Successful execution at 60% speed.
Day 3: Successful execution at 85% speed.
Day 7: Successful execution at 100% speed with 0 errors.

3.2 Stability

Post-intervention testing (1 week after cessation of stimulation) showed retention of the corrected pattern without the need for warm-up or stimulation (After-effects).

4. DISCUSSION

The dramatic reduction in learning time (from >6 months failure to 1 week success) suggests a synergistic effect. We hypothesize that Beta-tACS placed the M1-Cerebellar network in a state of "supervised learning," amplifying the error signal. The reduced velocity (Time Warp) prevented the activation of the "fast" erroneous sub-cortical loop, forcing the brain to use the stimulated cortical pathway to rewrite the motor program.

This protocol ("The Lioy Protocol") demonstrates potential for rapid correction of technique in elite sports and rehabilitation.

5. REFERENCES

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