Low Intensity Transcranial Electrostimulation Improves Human Learning of a Psychomotor Task

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ABSTRACT

People from all walks of life have long sought to reach new heights of expanded consciousness, improved prowess and personal enhancement. The search for means of improving personal performance using safe, convenient and non-invasive measures is receiving increasing attention with the advent of new electrotimulation devices such as the Alpha-Stim 350 used in this study.

This study addresses the question, "can low intensity transcutaneous electrostimulation (TCES) applied through the ear lobes significantly improve human learning and performance of a psychomotor task such as typing?" A double-blind, placebo control design was used. Seventy-eight subjects were randomly assigned to two groups: (1) the experimental (STIM) group which received electrostimulation while performing a computer typing game; and (2) the control (NSTIM) group, which did not receive TCES, but otherwise received the same treatment as the STIM group.

Statistical comparisons (t-tests) showed both STIM and NSTIM groups to be initially equivalent with respect to age, education and pretreatment performance. The dependent measure was the performance gain score obtained for each subject by calculating the score differential between the first and second trials. Statistical analyses demonstrated a significantly larger performance gain score for the STIM group over the NSTIM group as well as a significantly larger ultimate mean performance score.

The authors also postulated several modes of action for TCES and presented possible applications of electrostimulation as a performance enhancer in the fields of health, education, business and industry.

INTRODUCTION

The application of electric current to induce positive physiological effects in humans is not new or even a recent practice. Long before William Gilbert defined electricity in 1600, ancients recognized the therapeutic value of naturally-occuring electrical stimulation.[1] References to the use of Nile catfish (Malopteurus electricus) appear on wall reliefs of Egyptian tombs dating back thousands of years.[2] Aristotle and Plato reference the black torpedo (electric ray fish) prescribed in 46 A.D. by the physician Scribonius Largus for a variety of medical conditions from headache to gout.[3]

Although the origin of brain stimulation is generally credited to Leduc in 1902, the modern view of what has come to be called "electrosleep," "transcranial electrotherapy" (TCET), and "cerebral electrostimulation" (CES) began with the Soviet researcher Giljarowski in the early 1950's.[4] The initial studies in the Soviet Union and Europe were based on Pavlov's theory of cerebral protective inhibition. He proposed that a prolonged, monotonous weak stimulus applied to the central nervous

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system under comfortable conditions allow the brain cells to rest and permits restoration of function.[5]

Since that time a wealth of basic science research into the nature of electrical phenomenon is resulting in the formation of a new conceptual model of physiology based on an electrical biological control system.[6,7,8,9] From what we know to date, it appears that there is no biological function impervious to non-thermal, low-level electromagnetic fields. According to Becker, they are "a fundamental and pervasive factor in the biology of every living organism."[10]

Nearly all of the research examining the usage and effects of electricity are for diagnostic and therapeutic purposes. Using a similar stimulation procedure as in this study, Gibson and O'Hair found the Alpha-Stim to be significantly more effective than controls in reducing state anxiety and electromyographic readings of muscle tension.[11] Although these devices are also being used for non-clinical applications, there is a paucity of research using electrical technology in "well normal" populations.

A review of the literature reveals the virtual absence of prior experimental data on electrostimulation for learning and performance. The few impressionistic findings and anecdotal reports available do indicate, however, the possible utility of transcranial electrostimulation in enhancing mental functioning.[12] According to Hutchinson recent neurochemical and electromedical research suggests that TCES by new, low intensity devices such as the Alpha-Stim may promote the ability to think, absorb new information, combine ideas in new ways, consolidate facts into memory, and to recall information. In practice then, it may be used as a practical tool to increase learning.[13]

Historically and cross-culturally, people have sought to expand their consciousness, heighten creativity, elevate intellect and improve their mental ability. Many of the methods used to ostensibly promote mental prowess and personal performance have involved the use of unsafe drugs (e.g., hallucinogens), elaborate appliances (e.g., potentializers, floatation tanks), or stoic self-discipline (e.g., yoga, martial arts).

In writing about educational processes, Cratty described the five components of human performance as perceptual, motor, verbal, cognitive and basic behavioral supports (e.g., stress level).[14] He views learning as a task more dependent on internal loops (nerve networks) than external loops (behavioral conditioning/reinforcers of learning). This perspective seems compatable with current concepts in neurobiology emphasizing the relationship between learning and neurological events.[15] Gagne categorizes learning into eight types, the most complex of which is problem solving.[16] This requires combining previously learned rules (information) into new, higher-order rules (solutions). Important to the design of this study on electrostimulation and performance is Gagne's assertion that "the presence of the performance does not make it possible to conclude that learning has occured. . . it is necessary to show that there has been a change in performance."[17]

It can be concluded, therefore, that when performance improves by some measure over time, learning has taken place.

The purpose of this study is to evaluate a safe, practical means of improving mental functioning by examining the effects of electrostimulation on learning and performance in well-normal human subjects.

The various therapeutic terminologies used to describe non-convulsive electrical stimulation are inappropriate for the non-clinical application of electrical currents used in this study. Accordingly, the authors have coined the term "transcranial electrostimulation" (TCES) to describe the non-therapeutic application of low intensity current to the brain.

MATERIALS AND METHODS

Of the 103 individuals who responded to recruitment efforts, 21 failed to satisfy the inclusion criteria and/or declined participation when informed of the nature of the study. Of the remaining 82, four did not appear for their scheduled performance sessions. A total of 78 subjects completed the study.

There were 29 male and 49 female participants. Random assignment of 39 subjects to each of the two conditions produced an experimental (STIM) group with 15 males and 24 females, and a control (NSTIM) group with 14 males and 25 females. The subjects ranged in age from 18 to 45 years with a mean age of 32.4 years.

Most subjects (98.7%) were caucasian with a mean of 2.7 years of college. Nearly one-third reported a gross family income between $20,000 and $30,000 with another one-third earning less, and the remaining one-third earning more. Most subjects (96.1%) reported good to excellent health.

A project assistant maintained a master subject list and constructed N-th person samples by alternately assigning incoming subjects to STIM and NSTIM groups without knowledge of the researcher. The assistant also activated or deactivated a switch on the rear panel of the Alpha-Stim 350 prior to each performance session. These conditions kept the researcher "blind" to the conditions in which subjects were placed.

Subjects were oriented and instructed by the investigator (REM) in accordance with set protocols. They were seated in a comfortable chair in front of a computer monitor used to measure their performance. The temperature in the room was maintained at 70 to 72 degrees fahrenheit. Incandescent lighting was supplemented with indirect sunlight and a white noise generator emitting sounds simulating the ocean was used to reduce potentially distracting outdoor noise.

The Alpha-Stim 350, used in this study, is a new modality often referred to as "electromedical therapy" (EMT) that has evolved from traditional TENS through modifications in the waveform, frequency and intensity of stimulation. The Alpha-Stim 350 produces a biphasic DC modified square waveform with random factors to avoid accommodation by the nervous system. The Alpha-Stim is advantageous for use on the head because it generates a microampere current for milliseconds, whereas traditional TENS devices generate milliampere current for microseconds.

The performance measuring device was a Commodore 64 microcomputer system. Dependent variables (psychomotor performance) measurements were derived from the subject's execution of a computer game called "MasterType" by Scarborough. A keyboard overlay was fabricated so only the keys used were exposed. The subjects were instructed to try to push themselves to do their best. The importance of speed and accuracy were repeatedly emphasized.

The object of the game played by each subject was to destroy alien spaceships which moved in from each corner to the center of the screen where the subject's spaceship was located. If an alien reached the ship at the center of the screen, the subject's ship exploded and was then replaced. Each alien is represented by one of eight characters (A,S,D,F,J,K,L or :). To destroy an attacking alien spaceship, the subject had to type the correct character followed by a space bar. Aliens are also immediately replaced. Therefore, the best strategy is to destroy the aliens closest to the center of the screen.

The entire procedure lasted about 35 minutes per subject. The first ten minutes were devoted to subject orientation and form completion; the next 20 minutes involved application of electrodes, instructions, performance and recording; and the last five minutes were for debriefing and payment of a $5.00 participation award.

All procedures were implemented by a single investigator to minimize experimenter effects. The protocol was read to each subject to standardize the administration of experimental procedures including exposure time to electrostimulation and rest period parameters.

To create a double-blind procedure, all subjects were instructed that they would be receiving the treatment and had soft felt electrodes attached bilaterally to their ear lobes. They were informed that due to varying perceptual thresholds and individual tolerances, they may or may not feel a tingling or pricking sensation in their ear lobes. Subjects were instructed not to indicate, in any way whatsoever, any perception of TCES to the researchers, but if it became too uncomfortable, they could stop the study at anytime.

Both STIM and NSTIM subjects performed the first trial (t1) on the computer without stimulation. This allowed both groups to be compared for any initial differences in performance.

Immediately following the first trial, STIM subjects began receiving electrostimulation of 200 μA at 0.5 Hz while hearing new instructions. After this procedure the second trial (t2) commenced. Both groups played the same computer typing game twice more in close succession (Game 3 and Game 4). TCES induction periods of about four and ten minutes preceded the play of Game 3 and Game 4 respectively for STIM subjects.

The question this study addresses is, will there be a significant difference in performance on the dependent measure between the STIM group and the NSTIM group?

The null hypothesis is that there will be no statistically significant difference between the electrostimulation (STIM) group and the control (NSTIM) group on the psychomotor performance measures.

RESULTS

Performance products ("PPs") for each subject were obtained by multiplying rate (per minute) scores and accuracy (percent correct) scores following the subjects completion of each of the four games. Thus, values were obtained for PP1, PP2, PP3 and PP4.

The prestimulation mean of PP1 and PP2 was calculated for all subjects and recorded as PPt1 (performance product for the first trial). Following games 3 and 4 the mean performance product was recorded as PPt2 (postelectrostimulation for STIM subjects).

The dependent variable was the performance gain score ("PG") computed by taking the difference between t1 and t2 performance products. This is represented as:

$$PG = PPt2 - PPt1$$

In the following analysis, all significance tests were employed at the 0.01 confidence level.

Table 1 displays the summary of t-test comparisons of STIM and NSTIM groups based on age, education and PPt1 scores (pretreatment performance). The differences between means were not significant at alpha = 0.01, indicating the initial equivalence of the two groups.

Table 2 displays the summary of Chi-square comparisons of STIM and NSTIM groups based on race, sex, gross family income and reported general health status. There were no significant differences between groups, supporting the initial equivalence of the two groups.

Table 3 provides descriptive statistics for STIM and NSTIM groups on selected variables such as age, education, PPt1 and PPt2 means, performance gain (PG) scores and inter-game scores. Table 4 displays the results of t-tests performed on the dependent variable in relation to STIM and NSTIM groups. There were significant differences between groups in PPt2 means, performance gain (PG) scores and inter-game scores at alpha = 0.01.

Table 1. Summary of parametric tests for equivalence of Group "A" (Electrostimulated, hereafter called "STIM") and Group "B" (nonstimulated, hereafter called "NSTIM").

VARIABLE	t_{obt}	df	SIG?
Age	0.351	76	No
Years of College	1.174	76	No
Mean, Pretreatment Performance	0.196	76	No

(All significance tests were at alpha = 0.01.)

Table 2. Summary of nonparametric tests comparing of STIM and NSTIM groups.

VARIABLE	Chi^2_{obt}	df	SIG?
Race	0.00	1	No
Sex	0.00	1	No
Gross Family Income	2.21	4	No
Reported General Health Status	3.07	2	No

Table 3. Descriptive Statistics on Selected Variables.

VARIABLE	STIM MEAN	GROUP S.D.	NSTIM MEAN	GROUP S.D.
Age	32.6	6.9	32.1	7.1
Years of College	3.0	2.4	2.4	1.8
Mean Performance at t_1	14.0	4.3	13.8	4.6
Mean Performance at t_2	19.1	5.4	15.9	5.0
t_1 to t_2 Perfomance Gain	5.1	2.1	2.0	2.0
PP4-PP3	1.3	1.9	0.4	1.9
PP3-PP2	2.7	2.1	0.5	1.9
PP4-PP2	5.6	2.2	0.7	2.3

Table 4. Results of t-tests on dependent variables.

VARIABLE	t_{obt}	df	SIG?
Mean Performance at t_1	0.20	76	No
Mean Performance at t_2	2.73	76	Yes
t_1 to t_2 Performance Gain	6.65	76	Yes
PP4-PP3	6.24	76	Yes
PP3-PP2	4.69	76	Yes
PP4-PP2	9.56	76	Yes

The differences in performance gain score from t1 to t2 are graphically portrayed for STIM and NSTIM groups in Figure 1.

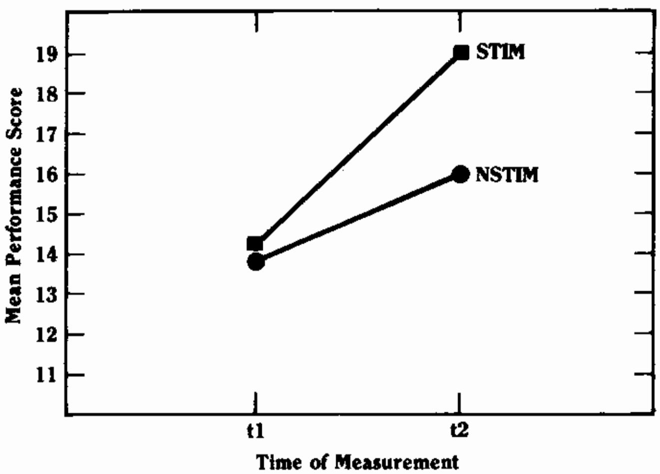

Figure 1. Performance Score Changes, t1 to t2

A decline in performance scores between Game 2 and Game 4 was experienced by 12 (30.8%) NSTIM subjects, whereas none of the STIM subjects performed more poorly on Game 4 than on Game 2.

Subjects' self-reports of TCES perception (tingling, pricking, or pulsing sensation in the ear lobes) revealed that placebo experience (hallucination) of sensation was evident in two (5.1%) NSTIM subjects. Nine (23%) STIM subjects reported no perception of the treatment (TCES) at all.

SUMMARY OF THE FINDINGS

The central concern of this study was to examine the effect of transcranial electrostimulation (TCES) on the speed and accuracy of performing a psychomotor task.

Statistical comparisons showed both STIM and NSTIM groups to be initially equivalent on the demographics of age, race, sex, education, income and reported health. It was also shown that both STIM and NSTIM groups were initially equivalent with respect to pretreatment performance (PPt1).

A significant (alpha = 0.01) performance gain (PG) for STIM subjects was demonstrated by t-test analysis of the dependent variable. The null hypothesis proposing no significant difference in performance between the two groups was rejected. It was shown in this study, that low intensity transcranial electrostimulation significantly enhanced the overall performance of a typing task.

It should be noted that three performance relationships were found to be statistically significant (alpha = 0.01) according to Table 4. They were:

PP4 - PP3 (Game 3 versus Game 4),
PP3 - PP2 (Game 2 versus Game 3), and
PP4 - PP2 (Game 2 versus Game 4).

PP1 was not examined because it mainly served as a trial and error learning period for subjects. The fact that these inter-game differentials were all found to be significantly different between STIM and NSTIM groups strengthens the findings that TCES improves performance.

Of special interest is the observation that the greater the length of exposure to simulation, the larger the obtained t value (at the same df). The resultant increase in statistical significance implies that a longer induction period for TCES (ten minutes for PP4 versus four minutes for PP3) is more effective in improving learning and performance.

Another noteworthy finding was the unexpected decline in performance for NSTIM subjects from Game 2 to Game 4 (PP4 - PP2). It was anticipated that both STIM and NSTIM subjects would improve on performance measures with repeated practice and greater task familiarity. This indeed was the case for STIM subjects. All STIM subjects did improve their performance from Game 2 to Game 4. Among NSTIM subjects, however, 30.8% declined in performance from Game 2 to Game 4. This suggests a possible fatigue and/or inattention factor in some unstimulated subjects which may have gained dominance over the familiarity and practice factors.

Successful results discovered in this study should be examined for intervening variables and alternative explanations. It appears that subjects vary greatly in their individual perception of TCES. In this study, nearly one-quarter of STIM subjects reported no sensation from TCES at 200 μA. Accordingly, not all subjects had the same exact subjective experience during the experiment.

Although a pilot study did reveal effectiveness with this modality at 100 μA, future research should investigate the optimum induction period, intensity and frequency levels. This study did not evaluate the residual effect, the parameters of which would ultimately determine correct dosages for TCES.

PROPOSED MECHANISMS

Prior to the time of this writing no other formal investigation has approximated the methodology used in the present study. Accordingly, comparison of methods and findings from similar studies is problematic. Other methodologically dissimilar studies have investigated the relationship between neurochemicals and learning. Flood showed that insufficient acetylcholine levels in mice cause reduced learning and intelligence and Sitaram demonstrated that raising acetylcholine levels in human subjects correlated with increased efficiency of memory and learning.[18,19]

Patterson and Capel suggested that each brain center generates impulses at a specific frequency based on the predominant neurotransmitters it secretes.[20] In experiments with rats, these investigators discovered that low frequency currents can cause as much as a threefold elevation of endorphin levels. Endorphins are thought to be involved with many phases of behavior such as pain, euphoria, stress, thirst, learning, certain forms of mental illness and aspects of pleasure and reward.[21]

Although endogenous opioid peptides seem to inhibit neuronal action (analgesia) in many brain regions, these very same substances actually excite neurons in the hippocampus, a limbic structure implicated in memory for recent events.[22] Routtenberg has noted that electrostimulation triggers the release of large amounts of neurotransmitters known as catecholamines (e.g., norepinephrine and dopamine).[23] Studies by Stein et al. showed enhanced learning and memory when norepinephrine levels were increased in appropriate parts of the brain.[24] Other studies indicate other neurotransmitters, including glutamate and serotonin, are involved in memory formation and learning.[25]

Bauer postulates a mechanism of tissue interaction with electromagnetic fields such that an EMF of the correct magnitude and frequency causes alterations in the molecular plasma membrane of cells, influencing membrane enzyme systems in much the same way as a chemical catalyst.[26] Electromagnetic fields, therefore, may act like hormones upon the membranes of brain cells, causing them to alter and grow in size and dendritic length.

An alternative mode of action for TCES is described by Brovar as the synchronization of brain hemispheres leading to a state of relaxed alertness.[27] Although alpha brainwaves would not likely predominate during a performance task with eyes open, brain hemispheric synchronization by TCES may contribute to improved concentration and efficiency of learning and performance.

TCES could involve the reticular formation of the brainstem and, with its extensive ascending and descending neural networks, the reticular activating system (RAS). The RAS is involved in producing a myriad of behavioral expressions from alertness to sleep.[28] This "attentional center" plays an important integrative role in the functioning of mind and body. Electrostimulation of the RAS may result in heightened attention, alertness and drive (resistance to mental fatique) possibly explaining the fact that all STIM subjects improved their performance from Game 2 to Game 4 (PP4 - PP2) whereas more than 30% of the NSTIM subjects suffered a decline in performance.

At this time, however, the mechanisms of action for TCES are not well defined nor clearly understood.

SUMMARY

Electrotherapy in general, and low intensity TCES have many important clinical applications in medicine and related fields. The findings of this study suggest that TCES may also have many useful non-clinical applications as well.

Since the results of this study demonstrate the efficacy of TCES in improving human learning and performance, the possible applications of this modality seem virtually unlimited. TCES seems well suited to education and training environments. Most directly related to this study might be the use of TCES by colleges and business schools to teach typing and word processing skills more expeditiously. Normal or learning disabled children might also be taught more efficiently under the immediate or residual effects of TCES in classroom settings.

More removed from this study might be the use of TCES in business and industrial environments to stimulate executive problem solving or improve workers' concentration, accuracy and speed. Police officers, automobile drivers, air traffic controllers, surgeons, pilots, athletes and others seeking increased alertness, concentration and performance may benefit from TCES.

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