A Study of the Effects of Cranial Electrical Stimulation on Attention and Concentration

SUSAN SOUTHWORTH, PSY.D.
The Family Institute and Associates

Abstract—There have been several anecdotal accounts that cranial electrical stimulation (CES) enhances attention and the ability to learn new tasks in a normal population, but only one published investigation confirms that CES improves attention using the Alpha Stim CES (Madden and Kirsch, 1987). The purpose of this study was to corroborate the findings of Madden and Kirsch, using more precise measures of attention, such as a Continuous Performance Test (CPT). A pretest and posttest CPT was given to two groups using the LISS CES device. The control group consisted of twenty-one subjects who received the placebo treatment. The experimental group of thirty-one subjects received twenty minutes of CES. Four measures of the CPT show significant gains in attention: Number of Hits, p =.010 Hit RT ISI Change, p =.016, Risk Taking, p =.055; and Attentiveness, p =.054. Based on subjects who demonstrated improvement by one standard deviation on two different measures of the CPT, thirty-one percent of the experimental group improved versus four percent of the control group. The use of CES as a method of increasing attention is a promising area that requires further investigation.

CRANIAL ELECTRICAL STIMULATION (CES) involves the application of small amounts of pulsed electric current using electrodes applied to the head. CES has been used in Europe and the United States for treatment of depression, anxiety, and insomnia for the past twenty years, and there have been several anecdotal accounts of how CES has been used to increase attention and concentration in normal subjects. These accounts include truck drivers using the device to increase concentration during times of long drives and students using the device to increase attention and concentration (Hutchinson, 1991).

History of Electrostimulation

The application of electric current in the healing arts is not new practice. Long before William Gilbert defined electricity in 1600, the therapeutic value of naturally occurring electrostimulation was used by the ancient Egyptians and the Greeks. The use of Nile catfish (Malopteurus electricus) is displayed on wall reliefs of Egyptian tombs dating back thousands of years. Aristotle and Plato reference the black torpedo, an electric ray fish, which the physician Scribonius Largus prescribed for relieving headaches and gout in 46 A.D. A similar application of electrical stimulation for relief of pain in the joints was described in 1747 using "an electrifying machine." The subject observed that the pain

Address for correspondence: The Family Institute and Associates 8301 State Line, Suite 216 Kansas City, MO 64114.

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decreased prior to retiring for the night after the first treatment, and by the third day, the pain disappeared (Braverman et al., 1992).

The therapeutic use of electricity did not gain widespread acceptance due to the difficulty of providing a suitable source of electric current. The technology needed to manufacture CES devices is relatively recent. The earliest account of the use of small amounts of low voltage current for therapy appeared in 1953 by the Soviet researcher, Giljarowski, who used CES for relieving insomnia and in the process coined the term *electrosleep.* Other terms used to describe the use of low voltage current to the head include *transcranial electrotherapy* (TCET) and *cerebral* or *cranial electrostimulation* (CES).

The first studies in the Soviet Union and Europe were based on Pavlov's theory of cerebral protective inhibition. This cortical inhibition (sleep) protects the cortical cells from working beyond their capacity. In other words, the Soviet investigators theorized that weak impulses of direct current applied transcranially would induce a sleep-like response and cause a calming effect on the central nervous system (Klawanski, 1995). Other studies have found that overworking of cortical cells is related to neurosis and various functional disorders (Weiss, 1973). Giljarowski proposed that a weak stimulus applied for a period of time to the central nervous system allowed the brain cells to rest and allowed for restoration of function.

Attention to cranial electrotherapy in the West was stimulated by the International Symposia for Electrotherapeutic Sleep and Electroanesthesia, held in Graz, Austria, in 1966 (Wagender, 1969, cited in Klawensky et al., 1995). The first studies appeared in the U.S. in the early 1970s. One cause for the late involvement of U.S. investigators was the absence of available equipment, which led to some researchers gaining access to Russian-made devices, while others constructed their own. By 1975, Brown reported seven different CES units being manufactured in the U.S. In terms of published research, the most productive years were between 1973 and 1977, when fifty journal articles and reviews appeared in print. The application of CES developed from use with those suffering from sleep dysfunction to treating anxiety when, in 1977, Ryan and Souheaver reported patients also benefited from CES while awake. The positive outcomes were measured as changes from pretreatment to post treatment anxiety scores.

Currently there are three commercial devices available for clinical application of CES (Liss, personal communication, October 1, 1998). In 1976, amendments to federal law regarding the U.S. Food and Drug Administration (FDA) brought medical devices that had already been marketed under FDA jurisdiction (Code of Federal Regulations, Title 21, Chapter 1). In 1989, the FDA amended its device regulations to require all medical devices that had not previously gone through a formal premarket approval process to do so. This process requires the submission of data adequate to support whatever claims of efficacy are to be made for the device and data supporting the safety of the device. More recently, the FDA has formally requested CES device manufacturers to comply with the requirement (Food and Drug Administration, 1993, as cited in Klawanski et al., 1995).

Treatment Effects

Researchers have reported mixed results in treating a number of conditions including anxiety, depression, pain, and insomnia through CES (Rosenthal and Wulfsohn, 1970; Feighner et al., 1973, Frankel et al., 1973, Passini et al., 1976; Smith and Day, 1977). This treatment possibility is important when one bears in mind that some drugs used to treat these ailments have undesirable side effects, can become addictive, or both.

Several published studies also report the LISS Cranial Stimulator is effective in relieving headache pain (Solomon and Guglielmo, 1985; Solomon et al., 1989). Another promising area of treatment is addiction, where CES has been used in the detoxification of opiate dependent patients. Alling, Johnson, and Ellmoghazy (1990) reported promising results with CES as a treatment method that may help alleviate drug withdrawal and cravings. CES has also been used as a treatment for anxiety experienced by chemically dependent persons (Schmitt et al., 1986; Patterson et al., 1994). In two studies of alcoholic inpatients, Smith (1982) found CES was associated with significant recovery of short-term memory loss and a significant improvement in cognitive functioning on the maze and form board subtests of the Revised Beta Examination of I.Q. Another promising use of CES is with phobia patients; Smith and Shiromoto (1992) found CES significantly reduced the intensity of the fear response in phobic patients.

There have also been promising results with the use of CES with brain injured patients. Smith, Tiberi, and Marshall (1994) examined the effects of CES on closed head-injured patients. CES ameliorated symptoms of tension, anxiety, depression, anger, fatigue, hostility, inertia, and confusion. Schmitt, Capo, Frazier, and Boren (1984) conducted a double-blind study on inpatient alcohol and poly-drug abusers with cognitive brain dysfunction and found significant gains on three subscales of the Wechsler Adult Intelligence Scale (WAIS) that are clinical indicators of organic brain syndrome. Significant gains were also made on the Army Beta I.Q. test among CES-treated patients. Wilson and Childs (1988) conducted a case study of four patients suffering from attention-to-task deficits in which CES was used over a three week period. The results showed significant improvement in the posttreatment scores.

There is a growing body of research in the use of the LISS Stimulator with Cerebral Palsy patients. Studies have shown an inhibition of primitive reflexes, increased motor learning, increased coordination, and increased hand function in children with the ailment (Malden and Charash, 1985). Logan (1988) also found the LISS Stimulator beneficial in reducing spasms in Cerebral Palsy patients.

The treatment effects of CES in almost all of its applications appear to be cumulative. Treatment for anxiety and depression, for example, requires a minimum of five to seven days of at least thirty minutes per day for lighter forms of the disorders and two to three weeks of daily 30–40 minute sessions to alleviate the more entrenched forms (Smith, 1982).

Effects of CES on the Central Nervous System

Several researchers have studied the effects of the LISS Cranial Stimulator on neurotransmitter production measured in blood plasma and cerebral spinal fluid. A study by Cady et al. (1989) measured blood plasma levels before and after the LISS Cranial Stimulator was used on normal subjects and depressed and chronic pain patients. Findings indicated serum levels of serotonin and beta-endorphin rise with CES over a two week treatment time. Cady et al. (1989) also measured neurochemicals in cerebrospinal fluid and blood serum in five asymptomatic subjects. Baseline measures where taken, and samples were taken ten minutes after twenty minutes of CES. Results showed beta-endorphin, serotonin, and melatonin increased in both plasma and cerebrospinal fluid after CES. The CES-induced plasma increases in melatonin, serotonin, beta-endorphin, and norepinephrine suggest CES activates a broad hypothalamic response, which may account for its benefit in the treatment of depression.

The most recent study that examined the effects of CES on the production of neurotransmitters was conducted by Liss and Liss (1996), the developers of the LISS Cranial Stimulator. The results of the Liss and Liss study indicated a significant increase in levels of serum concentration of serotonin and beta-endorphins after twenty minutes of transcranial stimulation over those in the placebo group. There were also elevations in the levels of GABA and DHEA, with decreased levels of cortisol and tryptophan. Closson (as cited in Liss and Liss, 1996), in a private experiment, drew blood samples periodically for two hours following twenty minutes of CES. Results showed ACTH rose an average of 75% over baseline within five minutes of stimulation, then gradually decreased to 25% over baseline by the end of two hours. Serotonin rose to 50% over baseline by twenty minutes and stayed at that level for the rest of the two-hour period. Beta-endorphin rose progressively from its baseline throughout the two-hour period, and cortisol gradually decreased 18% over the same duration of time.

Mechanism

The previous studies confirm CES alters neurochemical production. Although some research addresses the mechanism of how the low level of current emitted with CES alters the brain's neurochemistry, more research is needed. Liss and Liss (1996) began to address this important issue. Their research has shown stimulators were developed with the intent to match the dynamic electrical impedance of the body. Oscillographic recordings in human subjects following monopolar stimulation gave evidence of stored minuscule amounts of energy (less than 1 milliampere equivalent direct current in each work phase) indicating that internal currents are produced. This work led to an hypothesis that states the mechanism by which the neurotransmitter levels change includes an internal current, which is caused by modulated energy of the stimulator acting on the stimulated tissue.

Liss and Liss (1996) hypothesized that physiologically, while the factors for an action may be present, if the triggering energy is insufficient, then no action will occur. They furthermore suggest that, in some cases, introducing the current of the LISS Cranial Stimulator facilitates the physiologic action. The stimulator introduces this energy into the nervous system to demodulate the stimulator energy into the information the organism needs to help alter the neurochemical levels of certain substances.

Liss and Liss (1996) suggested that the release of energy by the modulated carrier technique used by the LISS Cranial Stimulator is converted in the body into an internal current by energy stored and facilitated by the bulk capacitance of the head and body. This may be the mechanism by which the modulated current alters neurochemical production.

Exactly how CES may increase attention is unclear. Theories are discussed by Hutchison (1991), and neurochemical and electromechanical research suggests CES may promote the ability to think and to retain and recall new information.

Norepinephrine is known to increase mental alertness; serotonin is thought to be involved in learning, mood, sleep/arousal, regulation of pain, and memory. Beta-endorphins also have a strengthening effect on learning. The increase of these neurotransmitters may be the cause of the increased learning, memory, and attention attributed to the use of CES. In experiments where norepinephrine levels in the brain were reduced, memory and learning decreased. When norepinephrine levels were increased in certain parts of the brain, memory and learning were enhanced (Stein and Belluzzi, 1975).

The role of endorphins in learning is described by Routtenberg (1978). Pleasure pathways are closely associated with areas of the brain known to be involved in learning and the formation of memory. Routtenberg speculated that pathways of brain reward may function as pathways of consolidation of memory. Perhaps this explains why one feels a mild sense of elation when learning something new. A neuroscientist, Pert (as cited in Weintraub, 1984), has proposed that endorphins are part of the reward system for learning.

Another theory, discussed by Madden and Kirsch (1987), is that CES may stimulate the reticular formation of the brain stem, which plays a role in sleep and arousal, attention, movement, and various vital reflexes. The neurons of the activating portion of the reticular formation are excited by sensory stimuli conducted by way of collaterals from the somatosensory, auditory, visual, visceral sensory system. When a novel stimulus is received, attention is focused on it while general alertness increases. This behavioral arousal is independent of the modality of the stimulation and is accompanied by electroencephalographic changes from low-voltage to high-voltage activity over much of the cortex (Waxman and deGroot, 1995). Electrostimulation of this region may increase attention and alertness and help resist mental fatigue.

Research on the Effects of CES on Attention

Although the use of CES for anxiety, depression, the treatment of cognitive brain dysfunction, and insomnia is well documented (Schmitt et al., 1986; Gibson and O'Hair, 1987; Wilson and Childs, 1988; Cady et al., 1989; Shealy et al., 1989, 1992), there is scant research in the area of CES increasing attention span and concentration in normal subjects. Madden and Kirsch (1987) addressed the research question: Can CES significantly improve learning and performance of a psychomotor task? The study employed two groups controlling for the placebo effect by using a double-blind study. The dependent variable used was a computer typing game. Both groups played the computer game without CES stimulation to obtain pretest data. A CES device was worn by both groups, and they were told they were receiving CES during the second testing, although the unit was only activated for the experimental group. The object of the game was to destroy alien spaceships, which moved toward the center of the screen. Each alien was represented by a specific key, which required the subject to press the correct key and the space bar to destroy the alien ship and gain a point. Four games were played over a ten-minute period. All points were added for each game. A significant difference between group mean test scores was found at the .01 level, indicating CES increased attention and concentration while performing a psychomotor task. Another noteworthy finding of the Madden and Kirsch (1987) study was that longer induction periods for CES were more effective in improving learning and performance. This study intended to test the findings of Madden and Kirsch (1987) using a more precise measure of attention, the Conners' Continuous Performance Test.

Methodology

Since the LISS Stimulator is considered a medical device by the FDA, the developer of the unit recommended this research project be reviewed and endorsed by a physician or chiropractor. David E. Sternberg, M.D., endorsed the investigation after reviewing the proposal, consent form, and exclusion criteria.

The study used an A-B design. The Independent Variable is the Cranial Electrical Stimulation. The Dependent Variable is the Continuous Performance Test. There were two groups of normal subjects. Both groups performed a pretest (used to obtain baseline data) and a posttest. The control group (NSTIM) did not receive CES stimulation; the experimental group (STIM) received stimulation. Both groups performed the Continuous Performance Test (CPT) twice. The STIM group was given the pretest, received twenty minutes of stimulation for the CES, waited twenty minutes, then performed the second trial of the CPT. The twenty–minute waiting period was needed because the increase in production of the neurotransmitters takes at least that length of time. The effects from the CES stimulation last for four hours (Liss, personal communication, April 30, 1997).

Samples Employed

Two groups (21 NSTIM and 31 STIM) were selected from recruitment efforts conducted at a Kansas City Public School, a software company, and a church. The subjects, males and females ranging in ages from eighteen to sixty, were recruited as volunteers and randomly assigned to the two groups. All of the subjects were from a nonpsychiatric population and were screened for general physical health, cerebral palsy, epilepsy, multiple sclerosis, attention-deficit hyperactivity disorder, inpatient history of drug or alcohol abuse, depression, and anxiety.

Instruments Used

Several instruments were used in the study. The Conners' Continuous Performance Test (CPT) was used to measure attention. The LISS Body Stimulator was the CES device. Two devices were implemented; one device was short-circuited and used for the control group. The Beck Depression Inventory-II (BDI-II) and the Beck Anxiety Inventory (BAI) were used to exclude subjects with mild and more severe symptoms of depression and anxiety (Beck et al., 1993, 1996).

Conners' Continuous Performance Test. Respondents were required to press the spacebar of the computer keyboard when any letter other than X appeared. The test is presented in a game-like format and starts with instructions. The letters displayed are about one inch in size and boldfaced. There are six blocks with three subblocks each of twenty trials. For each block, the subblocks have different interstimulus intervals (ISIs): one, two, or four seconds. Total administration time for the Standard test is fourteen minutes (Conners, 1995).

LISS Body Stimulator. The CES device used was the LISS Body Stimulator Bipolar Model No. SBL-502–B. Two units were employed. One unit was short-circuited for use with the control group. The unit specification information gives the following description of the waveform analysis:

> Modulated waveform . . . enables the microcurrent generated by the LISS Body Stimulator to utilize the body's own electrical characteristics. The carrier waveform of 15,000hz and the first modulated waveform of 15hz and the second modulated waveform of 500hz are transmitted simultaneously. Each positive burst of energy is followed by a comparable negative burst of energy equal and opposite polarity to the initial burst. (Medi Consultants, Inc., no date)

The unit is 4.5 inches long, 2.66 inches wide, and 1.0 inch high. It has two cables and two electrodes. Round sponges are made wet and placed over the electrodes when applied for use. The water in the sponge acts as an electrical conductor. A Velcro™ band is used around the head to hold the electrodes in place. The unit turns itself off after twenty minutes of stimulation. Contraindications listed on the unit specification sheet are demand-type cardiac pacemakers and using the stimulator over the carotid sinus and laryngeal and pharyngeal muscles or both. The safety of using electrical stimulators during pregnancy has not been established.

Procedures Followed

Testing was performed in various locations, such as office settings, the home, and a classroom. Approximately one third of the subjects were tested in one location under identical conditions at a local public school. In some cases noises, voices, or both were audible to the subjects. When this occurred, the researcher attempted to keep the conditions the same for the pretest and the posttest. The majority of the subjects were tested in a quiet room with minimal interference from outside noises. The procedures for this study were as follows:

1. Subjects read a brief explanation of the study and signed a consent form.
2. Each subject completed a questionnaire and the Beck Depression Inventory and Beck Anxiety Inventory. The questionnaire and inventories were scored and used to qualify the subject for participation in the study.
3. A coin was tossed to determine to which group each subject was assigned.
4. Each subject was given test instructions and performed the CPT practice test.
5. The electrodes of the CES device were placed just below the temples, and the subjects were told they might or might not initially feel a tingling sensation. Subjects in the experimental group had the unit set just below the level at which they might be expected to feel the tingling sensation. Control group subjects received the placebo unit, which emitted no electrical stimulation. Both units appeared identical to the subjects. When the units were positively engaged, the "on" light was activated and the green lights flashed. The stimulation was given for twenty minutes.
6. The posttest was performed about 20–60 minutes after stimulation. This variance in posttest time occurred due to the availability of the subjects and the limit of only one CPT. This variance was not considered detrimental to results because the effects of CES are reported to last from two to four hours.

Data Analysis

Statistical methods employed were split plot ANOVAS for each measure of the CPT, with one between factor, the group receiving stimulation and the control group, and one within factor, the pretests and posttests. Differences in the pretest and posttest *t*-scores were calculated for each subject. Subjects with a difference of at least one standard deviation on two measures of the CPT were considered as having significantly improved attention. This criterion was selected based on Conners's statement regarding the number of measures from the CPT used to determine if a problem in attention exists (Conners, 1995). The NSTIM and the STIM groups were composed using the total number of subjects in each group who showed the level of clinical improvement.

Results

Significant results were found on four of the thriteen measures of the Conners's Continuous Performance Test indicating improvements in speed, accuracy, and improved accuracy over time in the STIM group. The four measures were Number of Hits, Hit RT ISI Change, Risk Taking, and Attentiveness. *F* and *p* scores are listed below for each measure:

1. Number of Hits	$F = 7.05$,	$p = .010$
2. Hit RT ISI Change	$F = 6.13$,	$p = .016$
3. Risk Taking	$F = 3.84$,	$p = .055$
4. Attentiveness	$F = 3.86$,	$p = .054$

The four measures listed above revealed the NSTIM group experienced a decline in attention in the posttest, whereas the STIM group increased ability to attend. The decline of attention in the control group may be explained by negative practice effects as described by Conners (1995). Conners suggests such negative practice effects on the CPT may be due to the demands on one's ability to attend to a boring task.

Proportions were calculated based on the criteria of subjects who demonstrated improvement by one standard deviation on two different measures of the CPT. One of twenty-one in the NSTIM group and ten of thirty-one in the STIM group met the criteria.

Discussion

The results of this study indicate that CES significantly improves attention and concentration in a normal adult population. The findings of this study confirm those found by Madden and Kirsch (1987) and also provide additional data on the effects of CES on attention.

There were four main differences between this study and those done by Madden and Kirsch (1987): (a) the duration of time CES was administered to the subjects; (b) the conditions under which the posttest was conducted; (c) the dependent variable; and (d) the LISS Body Stimulator was used in this study as compared to the Alpha Stim used in the Madden and Kirsch study.

The first two changes were based on a personal communication with the developer of the LISS Body Stimulator (Liss, personal communication, April 30, 1997) and the findings of Closson (as cited in Liss and Liss, 1996). The CES was administered for twenty minutes in this study versus ten minutes in the Madden and Kirsch study. Closson discovered the peak changes in neurochemicals affected by the LISS Body Stimulator occurred after twenty minutes of stimulation, and the increased levels were sustained for two hours.

The second change in methodology was conducting the posttest after a minimum waiting period of twenty minutes, unlike the Madden and Kirsch (1987) posttest, which was conducted while the ten-minute stimulation was administered. The improved attention scores on the CPT after the twenty-minute waiting period indicated that the effects of the LISS Body Stimulator on attention go beyond the time of direct stimulation. Exactly how long the effects on attention would last is not known; however, it may be similar to the time the neurochemicals sustain their altered production. It is noteworthy that during this study, posttest results of both groups were performed anywhere from 20–60 minutes after stimulation.

The third main difference between the two studies was the dependent variable: the CPT versus a computer game. The CPT was chosen because it is specifically designed to measure several indicators of attention (Conners, 1995), providing more measures and precision than computer game scores.

The fourth difference between the two studies was the CES unit that was used. The Madden and Kirsch (1987) study used the Alpha Stim, whereas this study used the LISS Body Stimulator.

When comparing the Madden and Kirsch (1987) findings to those of this study, two findings were similar: (a) improved accuracy and (b) the control group experienced a fatigue factor, whereas the experimental group maintained alertness. The Madden and Kirsch computer game performance scores increased in the STIM group over time and gradually declined in the NSTIM group. These findings are similar to the increase in the Number of Hits ($p = .010$) found here. The Madden and Kirsch study also demonstrated an unexpected decline in performance of NSTIM subjects from Game 2 to Game 4. Similar findings were found here, with a decline of mean scores in the control group in four attention measures (Number of Hits, Attentiveness, Risk Taking and, Hit RT ISI).

Results suggest an overall increased alertness and improved cognitive acuity of the subjects in the experimental group. For example, Hit RT ISI Change demonstrated faster reaction times in the experimental group as the time between targets increased, whereas the control group's response time became slower. This may be due to maintained alertness by the experimental group, whereas the control group became more fatigued. Subjects responded more frequently in the STIM group (Risk Taking, *B*) and demonstrated an increased perceptual sensitivity, which is a measure of the ability to discriminate targets from nontargets (Attentiveness, *D*). This may occur by CES raising cortical tone and keeping the brain alert so it is able to discern more quickly between targets and nontargets.

The findings of both this study and that of Madden and Kirsch (1987) suggest CES may have useful nonclinical applications in the fields of education, business, and industry. Improved attention may result in an increase in speed and accuracy while performing a task. Another important finding of both studies is the extended length of time an individual can perform a task with sustained accuracy and speed.

The application of enhancing attention with CES shows promise in a number of areas. For example, word processing and other computer-related tasks might be taught and learned in a more timely manner with an increase in accuracy. Students may find the device helpful when studying for exams, writing papers, or memorizing information. In the business setting, word processor operators using CES may increase their accuracy and speed in routine tasks. Computer programmers may find using CES while writing and debugging programs increases their accuracy and ability to attend for longer periods of time.

Further research on the effects of CES on attention would also be useful in a clinical population comprised of subjects suffering from attention deficits due to attention deficit disorder, brain injury, Alzheimer's disease, dementia, and cerebral vascular accident. Previous studies have proved CES effective in ameliorating symptoms of tension, pain, anxiety, depression, and confusion of head-injured patients (Smith et al., 1994).

Summary

To summarize, this study found results similar to those of the Madden and Kirsch (1987) study, demonstrating a significant improvement in accuracy and alertness. It has also added to the existing body of knowledge on how CES affects attention: (a) the effects of CES on attention are sustained past the time of stimulation; (b) increased perceptual sensitivity to targets; and (c) faster reaction times as the time between targets increased. Further research is needed to determine why certain measures of the CPT found significant results when others did not. Additional studies are recommended to evaluate the effect of CES on auditory attention and cumulative effects.

Although this investigation was centered around a normal adult population, it may serve as a basis for further research using CES with patients suffering from medical conditions that adversely affect their ability to attend and sustain attention.

Note

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