Comparative Effects of Microcurrent Stimulation on EEG Spectrum and Correlation Dimension

MICHAEL S. HEFFERNAN

Abstract—Two mathematical derivatives of electroencephalogram (EEG), Fast Fourier Transform (FFT), and correlation dimension from chaos analysis were used to assess the objective effects of earlobe versus mid-trapezius microcurrent stimulation on brain EEG. These measures were considered to be clinically relevant since low points in the FFT have been associated with attention deficit disorder, and declining correlation dimension has been associated with onset of epilepsy. Thirty Subjects (30) were assigned randomly to one of three groups: earlobe, trapezius, and a double blind placebo control Earlobe stimulation (CES) was hypothesized to alter BEG since research suggests CES enters the brain directly, through a perineural or vascular path via the auditory meatus. Results showed that trapezius microcurrent therapy proved more effective in producing significant declines in FFT spectral smoothing, with an average standard deviation (SD) in the FFT of 1.1, as compared to the CES group showing an SD of 2.9. Correlation dimension in both trapezius and CES stimulation groups increased significantly ($p<.001$) as compared to placebo, with the correlation dimension measures for earlobe, trapezius, and placebo being 5.7, 5.6, and 3.7, respectively. The author discusses the significance of using body points for promoting clinically beneficial effects in brain electrophysiology as evidenced by improved FFT and correlation dimension.

MICROCURRENTS APPLIED to the ear lobes, termed Cranial Electro-Stimulation (CES), produce 100 to 600 microamperes, with most devices being set at currents of a few hundred microamperes. Several research studies have been conducted to show the positive effects of CES in treating a range of disorders, including anxiety (Klawansky, 1995), depression (Shealy, 1989), pain (Morrison, 1994), elevated EMG (Heffernan, 1995), and HIV, immune T-4 deficiency (Schummer, 1995). Kirsch (1996) has summarized an extensive listing of research studies supporting the clinical use of CES. Liss (1996) measured significant increases in plasma levels of beta-endorphins, serotonin, and DHEA, with concurrent significant decreases in cortisol levels following microcurrent stimulation to ear points.

Microcurrents generated in CES are thought to reach the brain directly by conduction through the tissues of the external ear. Electrodes implanted in monkeys show that over 42% of CES currents enter the brain from ear stimulation (Jarzembski, 1970). Another investigation of capacitance changes measured between earlobe points following CES showed significant capacitance changes, indicative of increased parallel capacitive circuits in the brain (Heffernan, 1995). These observations suggest that CES may exert its influence not by skin receptors, but by some form of direct internal tissue transmission mechanism. Becker (1990) has summarized research in support of a perineural electrical transmission system that traverses the neuron sheath. The Becker perineural direct current (DC)

Address for correspondence: Michael S. Heffernan, 1807 HWY 35, North Rockport, Texas 78382.

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system maintains body polarity, acting as a semiconductor system confirmed by measurement of the "Hall Effect." Low current, externally applied ELF (10–20 Hz) has been shown to bypass skin receptors, maintaining frequency specific effects on calcium ion efflux in CNS neurons (Becker, 1990). Such frequency specific calcium efflux would not be possible if externally applied microcurrents were transduced into neuron spike potentials, because frequency specific cyclotronic resonance effects would be lost. Therefore, some evidence exists that CES, and other external fields, are carried perineuraly from external locations on the body. The current study was constructed in part to test this direct frequency transmission or perineural model by measuring EEG changes from CES versus longer route transmission from the shoulder area. It was hypothesized that greater changes in EEG would be seen when a 100 microampere, biphasic DC, CES signal traveled a shorter distance to the brain than that from the shoulder, where greater resistance would reduce treatment voltages on arrival at the brain

The author wanted to select EEG-dependent measures that would reflect high measurement reliability and that had some clinical relevance. Two such measures were selected: 1) the Fast Fourier Transform (FFT); and 2) nonlinear, system dynamic measure of correlation dimension. The EEG, FFT is defined as the RMS amplitude of the EEG at each one hertz band width in the EEG signal. Correlation dimension is defined as the number of dimensions in "N" space needed to represent and define an "attractor" or topographic image of the successive EEG data trajectories, data trajectories being generated as vectors from successive relative EEG amplitudes. The reader is encouraged to read Sprott and Rowlands (1992) as a good source for chaos techniques. As an application of system dynamics, the correlation dimension provides a measure of informational complexity of the EEG as a cybernetic signal. Correlation dimension distinguishes the informational content of the EEG as different from just stochastic noise in which the EEG trajectory would uniformly fill all of the phase space (Sprott & Rowlands, 1992). The author has run several pilot computations of correlation function, showing EEG data is more indicative of chaos than noise.

For several years the FFT has been the tool of neurofeedback practitioners in determining which region(s) of the patient's EEG to enhance through biofeedback. Clinical outcome studies using neurofeedback of EEG bands selected as low in the patient's pretreatment FFT typically show patient improvement for disorders such as attention deficit, anxiety, and addiction (Lubar, 1995). Declining correlation dimension and collapsing phase plots of the EEG have been related to pathologic states such as epilepsy and drug induced anesthesia (West, 1990; Bassingthwaighte et al., 1994). Likewise, increasing correlation dimension has been associated with increased awareness, problem solving, and REM sleep (Bassingthwaighte et al., 1994). In the current study it was considered a clinically positive sign when either the FFT showed an increase in low amplitude regions (spectral smoothing), or when correlation dimension increased.

Method

Subjects

Thirty subjects were randomly assigned to one of three conditions: 1) microcurrent stimulation applied bilaterally to the mid trapezius, with inactive electrodes attached bilaterally to the earlobes; 2) microcurrent stimulation applied to the earlobes, with inactive electrodes attached bilaterally to the trapezius; and 3) a placebo control group, all of whom had inactive electrodes attached to both earlobe and trapezius locations. All subjects were selected from the author's pain control practice, based on agreement after informed consent to enter into a study to test "the effects of very small electrical signals on brain EEG." All patients, when informed, elected to participate. Subjects were told they would be informed of the study results and would be allowed to receive any benefits derived at the conclusion of the study. Subjects were between the ages of 40–70 years, having a mean age of 65 years, sex distribution being 18 females and 12 males. Subjects' typical symptoms included head, neck, and shoulder pain of several year's duration. Seventy-five percent of the subjects were diagnosed as hating some level of auto-immune disease, mainly of a rheumatoid type. All subjects also displayed symptoms of slow wound healing, fatigue, and periodic "flare-ups" of joint inflammation, causing restriction in movement of various major joints.

Double blind was achieved by hating an assistant, out of sight of the experimenter and subject, turn the undisclosed location of stimulation on or off. The determination as to which site—earlobe, trapezius, or neither—were to be stimulated was made by the assistant, using a random numbers table. The assistant kept track of which sessions were placebo or treatment until after data analysis. Prior pilot studies by the author have shown that, when microcurrent stimulators are adjusted to approximately 100 microamperes of output, subjects do not sense the currents used, therefore maintaining the reliability of blinding (Heffernan, 1995).

Materials

Alpha-Stim 100, CES stimulators from Electromedical Products International Inc., Mineral Wells, Texas, were used in the current study. To achieve a subliminal output, stimulators were adjusted to the level of 100 microampere, variable biphasic spike wave set at an average of .5 cps. Stimulators were placed out of view of the patient and researcher. CES earlobe electrodes used on all subjects consisted of gold-plated, cotton-padded, constant spring tension ear clip electrodes. Cotton pads were saturated with tap water and placed on superior and medial portions of both ear lobes. Trapezius treatment was delivered by 1 inch, silver-silver chloride, sticky disk electrodes that were bilaterally applied to the midpoint of the trapezius muscle. The impedance of both trapezius and earlobe groups were equilibrated using an in series microampere meter and adjusting current levels in all subjects to 100 microamps.

EEG data was collected by a two-channel, J&J, Electronics, I400, computer interface, with optical isolator. The digitalized signals were fed into a 486 Dx, 100 MHZ computer. Spectral analysis was accomplished with a Russian designed software, "neurodata (ND2)" and purchased from API, Inc., Washington State. For computation of EEG correlation dimension, the tangent slope of log R vs. log CD(R) was computed from a Chaos Analysis program, provided by Dr. Robert Hilburn, Department of Physics, Amherst College, MA.

In all subjects, a two-minute baseline, EEG sample was taken after subjects came to rest in a sitting position for five minutes. This was followed by administration of a ten-minute treatment, or placebo condition, finally followed by another two-minute, post-collection period of EEG data. The EEG data for spectral analysis was averaged over a two-minute period. Pilot studies of various spectral curves show that a time period less than two minutes reduces the retest reliability of averaged FFTs below .75. Sampling periods longer than two minutes were found to average out important individual differences in spectral FFT. Spectral variability was measured by computing the square root of the average

TABLE 1
Post-treatment Standard Deviations in EEG, FFT, in earlobe trapezius, and placebo groups showing statistical, two-tailed, t-Tests, and level of significance.

	EAR	*TRAPEZIUS*	*PLACEBO*
	3.2	0.8	2.4
	2.8	1.0	3.7
	2.6	1.1	1.9
	3.1	0.9	3.0
	2.4	1.1	2.1
	4.0	0.4	3.2
	2.6	1.2	1.7
	3.6	1.1	2.3
	2.3	1.0	1.9
	2.5	2.0	2.7
x	2.9	1.1	2.5
SS	2.8	1.5	3.8
t*	1.4	5.7	—
	p> . 10	p< .001	

* t-Test between treatment and placebo group

squared deviations from the mean spectral amplitude of each subject's two-minute spectral record. Deviations were computed for each one cycle per second band width, going from 2 to 30 CPS.

By transforming two-minute EEG data accumulated on the neurodata program into ASCII format, four thousand data points were generated for each subject, representing successive EEG amplitudes in the two-minute EEG records. This data was then fed into a mathematical Chaos program for determination of correlation dimension. Correlation dimension was computed from the mid-slope of the log of (R) versus log CD(R) using the 10th embedding dimension, and 4000 data points. This procedure typically produces slopes of the function log (R) versus log Cd(R), with correlation dimensions that are reliable within 5–8%.

Results

Spectral Data

EEG (FFT's) were seen to significantly "smooth" following trapezius treatment with the microcurrent stimulator (see figure 1). The earlobe treatment group receiving traditional CES did not show any immediate spectral smoothing following treatment. The results of calculated Standard Deviation (SD) in post-treatment FFTs for the earlobe, trapezius, and placebo conditions are shown in Table 1. Smoothing of EEG spectrum, indicated by a reduction in the FFT, SD, was repeatedly observed in the post-treatment PFTs for the trapezius treatment group, but was not observed in either placebo or earlobe treatment conditions.

Chaos Data

Significant increases in EEG post treatment correlation dimension were found in both

TABLE 2
Post-treatment EEG correlation dimension in earlobe, trapezius and placebo groups showing statistical, two-tailed, t-Tests, and level of significance.

	EAR	*TRAPEZIUS*	*PLACEBO*
	5.5	6.3	3.5
	6.0	4.9	3.8
	5.2	5.4	4.1
	5.8	4.8	4.3
	6.1	6.3	4.6
	6.9	5.7	3.2
	5.2	5.9	3.1
	4.9	6.0	4.1
	6.1	5.5	3.5
	5.9	5.1	3.6
$\bar{X}$	5.7	5.6	3.7
SS	3.1	2.7	2.2
t*	8.3	8.2	—
	$p < .001$	$p < .001$	

trapezius and earlobe treatment groups when comparing both to the placebo control. These results are summarized in Table 2.

All subjects receiving trapezius and earlobe treatment, were significantly higher in average post-treatment correlation dimension as compared to placebo.

Discussion

The finding that earlobe stimulation did not produce greater effects on the EEG than did trapezius stimulation suggests that trapezius microcurrents may in fact be conducted without energy loss in route to the brain. Energy loss in the microcurrent signal may be prevented by capacitive storage of charges from microcurrents in the neuron myelin sheath, thereby assisting conduction of the microcurrent signal. Another explanation is that the resistance drop in treatment voltage in going from the shoulder area is insignificant in diminishing EEG treatment effects. If, as is suggested from prior studies, CES is more than a peripheral receptor stimulus, then the same seems probable for body point stimulation, since this study's results show that microcurrents to a body point are more effective in altering the EEG than is CES. If the EEG effects observed in the current study were a mere function of peripheral receptor stimulation, then numerous tactile and proprioceptive stimuli bombarding the subjects would have maximized FFT smoothing and correlation dimension increases before microcurrent stimulation. The data did not support this contention since patients significantly raised correlation dimension and evidenced FFT smoothing following microcurrent stimulation.

Results indicated a positive treatment response from both earlobe and trapezius microcurrent stimulation shown by increased correlation dimension. The observed increase in correlation dimension resulting from microcurrent stimulation indicates the future utility in treating abnormal electrical patterns in the brain by the application of microcurrents. Schiff (1995) has effectively blocked epileptic seizure patterns in rat brain tissue by applying a volley of microcurrent spikes at specific moments when EEG was determined susceptible by chaos analysis; that is, when the eigenvectors approached the "fixed attractor"

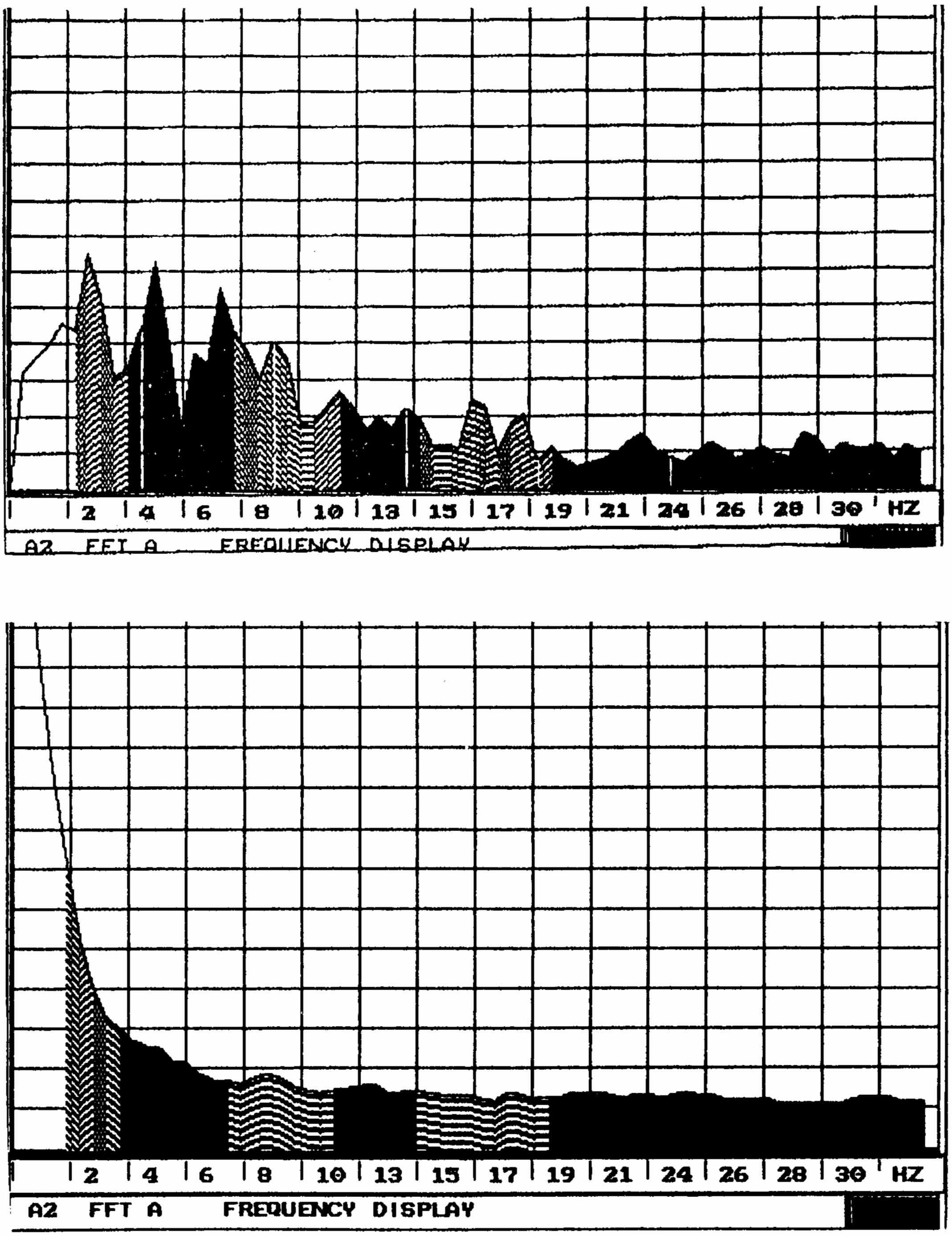

FIG. 1. Sample Pre- and Post-trapezius treatment FFT for sample subject 5. FFT's were based on two minute averaged EEG RMS amplitudes on the vertical axis, and EEG frequency on the horizontal axis.

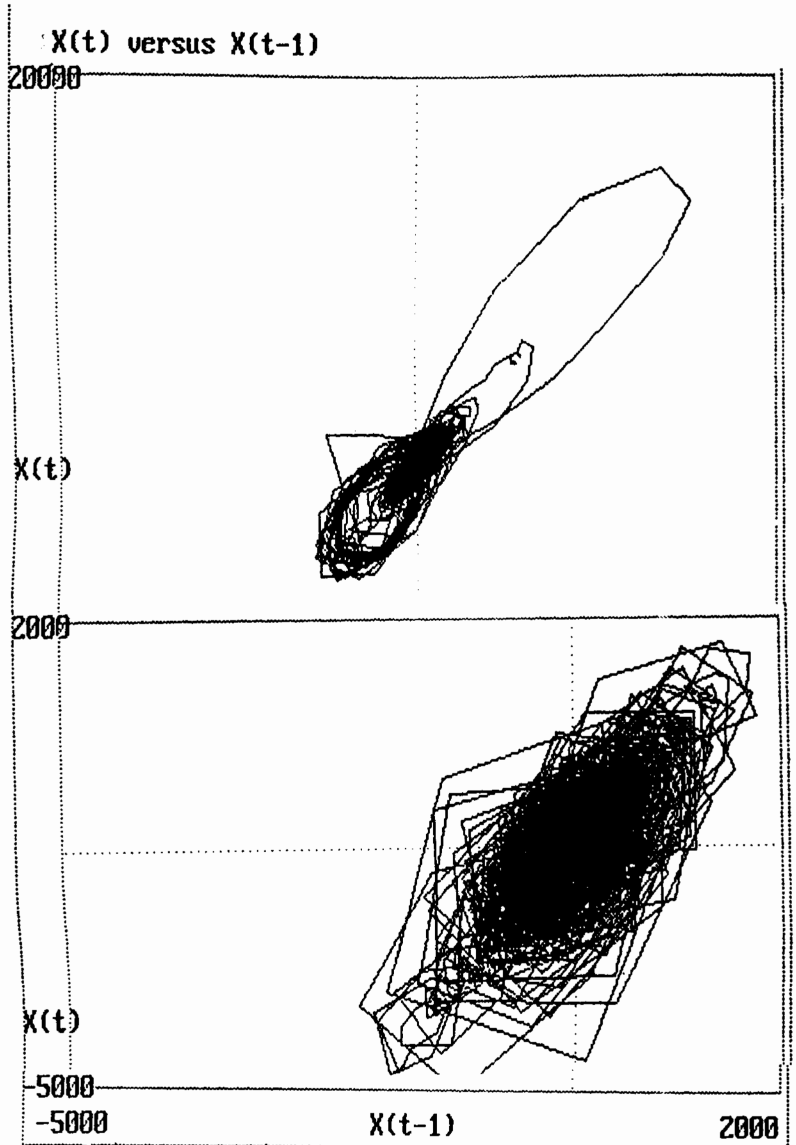

FIG. 2. Sample Return Plots of EEG Trajectories for subject 1, before and after trapezius microcurrent stimulation. Correlation dimension before treatment was 4.2 (top view); correlation dimension after treatment was 6.3 (bottom view).

or "unstable manifold." Without such a volley of microcurrents Schiff found epileptic patterns would follow. As correlation dimension increases in EEG data, the eigenvectors traverse many more paths, "avoiding a collapse" into fixed point attractors and resultant pathologic brain electrical patterns. Therefore, the correlation dimension increases in the present study would indicate fewer EEG eigenvectors approaching a fixed point attractor, and thus less possibility for pathologic brain patterns. This relationship of eigenvector concentration and correlation dimension is seen in looking at return plots in the current study before and after microcurrent stimulation. Those return plots having higher correlation dimension after microcurrent stimulation are expanded away from fixed points and are more symmetrical in appearance (see figure 2).

In contrast to Schiff (1995), who used precise timing to sensitive points in the EEG record to determine when to deliver constant frequency microcurrents, the current study employed a chaotic-like signal on a continuous basis to provide a similar effect. The microcurrent device used in the present study produced a continuously changing, chaotic-like, biphasic interval that averaged .5cps. This study's effects on raising return plot complexity and correlation dimension may therefore only apply to microcurrent devices that have complex or chaotic wave length spikes. Not all commercially available stimulators have such a parameter.

Since EEG effects were found at only 100 microamperes, further research is needed to determine the effects of TNS devices that use significantly higher current levels. Without such testing there is no indication that such higher current devices are without risk in disturbing electrical patterns of the brain.

Significant changes in FFT of the EEG, represented as spectral smoothing, followed trapezius microcurrent stimulation, suggesting a clinical application of body microcurrent therapy to treat low amplitude FFT bands associated with anxiety disorders (5–12 Hz) and attention deficit disorder (12–14 Hz). This would represent a possible cost-effective alternative to neurofeedback in treating these conditions. The possibility of using microcurrent therapy to treat anxiety or attention deficit disorder is based on the assumption that raising low regions in the FFT is sufficient to resolve such disorders. The Klawansky (1995) meta-analysis, showing CES as an effective treatment for anxiety, plus the work of Lubar (1995), lends some credence to this assumption.

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