Fractal Analysis of EEG Upon Auditory Stimulation During Waking and Hypnosis in Healthy Volunteers

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FRACTAL ANALYSIS OF EEG UPON AUDITORY STIMULATION DURING WAKING AND HYPNOSIS IN HEALTHY VOLUNTEERS

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Abstract: The authors tested fluctuation analyses (DFA) of EEGs upon auditory stimulation in waking and hypnotic states as related to topography and hypnotizability. They administered the Hypnotic Induction Profile (HIP), Dissociation Experience Scale, and Tellegen Absorption Scale to 10 healthy volunteers and measured subjects’ EEGs while the subjects listened to sounds, either selecting or ignoring tones of different decibels, in waking and hypnotic states. DFA scaling exponents were closest to 0.5 when subjects reported the tones in the hypnotic state. Different DFA values at C3 showed significant positive correlations with the HIP eye-roll sign. Adding to the literature supporting the state theory of hypnosis, the DFA values at F3 and C3 showed significant differences between waking and hypnotic states. Application of auditory stimuli is useful for understanding neurophysiological characteristics of hypnosis using DFA.

Hypnosis, a specific type of concentration that is inducible by the self or another, is essentially a wakeful neurophysiological state characterized by decreased peripheral consciousness in response to signals and the resultant attentive, receptive, and intensive focal concentration (H. Spiegel & Spiegel, 1978). Human consciousness can change in various ways during a day, and, even in a wakeful state, an individual’s degree of consciousness can differ according to whether their attention concentrates on a point or perceives the whole of their surroundings. Depending on their degree of peripheral and focal consciousness,

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humans have experiences in their daily lives that resemble the hypnosis phenomenon and can experience hypnosis in the absence of hypnotic induction by others (Barabasz, 2005/2006; H. Spiegel & Spiegel, 2004).

Researchers have proposed various theories to explain the hypnosis phenomenon. Long ago, hypnosis was regarded as a psychological or spiritual phenomenon with a magnetic aspect. Because most research methods addressing hypnosis relied on the subjects’ reports and on objective observation of their behaviors, explaining hypnosis scientifically and specifically was difficult (Hilgard, 1965). For the last several decades, however, many researchers have tried to explain hypnosis from a scientific, neurophysiological aspect. In one such effort, researchers began studying hypnosis via electroencephalograms (EEG) and brain imaging. Early studies that analyzed the hypnosis phenomenon by means of EEGs evaluated brain waves by employing naked-eye observation, while later researchers employed computers to quantify brain waves or performed linear analyses on them, such as spectrum analysis using Fourier transforms.

The early studies using linear analyses of EEGs to examine hypnotizability and the hypnosis phenomenon commonly reported associations between hypnosis and the theta wave and that theta wave density was higher in those with high hypnotizability than in those with low hypnotizability (R. Freeman, Barabasz, Barabasz, & Warner, 2000; Graffin, Ray, & Lundy, 1995; Sabourin, Cutcomb, Crawford, & Pribram, 1990; Tebecis, Provins, Farnbach, & Pentoey, 1975). Results regarding alpha and beta waves were inconsistent. With regard to the theta wave, some researchers reported hypnosis generally associated with right hemisphere. However, no studies reported a consistent anatomical association (Crawford, Clarke, & Kitner-Triolo, 1996; De Pascalis & Imperiali, 1984). More recently, researchers have reported an association between 40 Hz brain waves and the hypnosis phenomenon (De Pascalis, 1993; De Pascalis, Marucci, & Penna, 1989; De Pascalis, Ray, Tranquillo, & D’Amico, 1998). To sum up, linear analyses of EEGs have many controversial points and limitations with regard to explaining the hypnosis phenomenon and hypnotizability (Ray & Tucker, 2003).

Despite these earlier efforts, however, researchers have had difficulty identifying the neurophysiological concomitants of the hypnosis phenomenon, mainly because of the cerebral nervous system’s complexity, in which it resembles other biological signals in the body. Because researchers can see only the gross results of the cerebral nervous system’s complex mechanisms, understanding the system (which, as in most natural phenomena, involves both accidental and deterministic factors) using only deterministic and linear methods is difficult. Since Mandelbrot presented the concept of fractal dimensions in the 1960s, research has seen the introduction of nonlinear analysis methods for
natural phenomena, and researchers have begun to apply such analysis methods to biological signals, such as electrocardiograms (ECGs) (W. J. Freeman, 1987; Peng et al., 1993; Peng, Havlin, Stanley, & Goldberger, 1995). The “chaos” nonlinear analysis method allowed new insights into EEG analysis by revealing that biological signals, such as brain waves and heartbeats, may look like accidental, random noises but, in fact, express regular but unpredictable patterns of information in the backgrounds of biological processes (Lutzenberger, Elbert, Birbaumer, Ray, & Schupp, 1992; Ray, 1997).

Among the various nonlinear analysis methods, researchers have found detrended fluctuation analysis (DFA), developed by Peng et al. (1995), to be useful for finding long-range temporal correlations in non-stationary time series. Recently, DFA use in nonlinear analyses of EEGs has been increasing. Such studies have reported that brain waves do show long-range temporal correlations (Jiang, Ning, An, Li, & Feng, 2005; J. M. Lee, Kim, Kim, Park, & Kim, 2002; Linkenkaer-Hansen, Nikouline, Palva, & Ilmoniemi, 2001; Linkenkaer-Hansen, Nikulin, Palva, Kaila, & Ilmoniemi, 2004; Nikulin & Brismar, 2004, 2005). “Long-range temporal correlations” means the dynamic system of brain waves shows power-law behavior. Moreover, this suggests the background neurodynamic systems are similar at different time scales and that the part is similar in structure to the whole, with the self-similarity characteristics showing a fractal pattern (Bassingthwaighte, Liebovitch, & West, 1994). If the long-range temporal correlations show different patterns according to the brain’s mental condition, then, presumably, specific neural circuits, differing from one another, also rule its dynamic system. Furthermore, in the case of a long-range temporal correlation showing topographic differences, it is likely affected by specific mechanisms related to given neuronal processes (Nikulin & Brismar, 2005).

Accordingly, researchers can study the hypnosis phenomenon and related neurophysiological concomitants using DFA. In their research using DFA, J. S. Lee, Spiegel, et al. (2007) reported that the hypnotic and wakeful states differed in their neurophysiological mechanisms. And there were some previous studies about the EEG analyses upon attention task or auditory stimulation in the nonhypnotic state (Galbraith, Olfman, & Huffman, 2003; Marshall, Mölle, & Bartsch, 1996; Schröger, Giard, & Wolff, 2000), but there was no study using DFA upon auditory stimulation in hypnotic and nonhypnotic states. As with previous research using DFA with hypnosis, this study analyzed the EEG signal trends upon auditory stimulation in the waking and hypnotic states, using fractal analysis to identify the neurophysiological concomitants of hypnosis. Another important aspect of describing neuronal dynamics is the long-range temporal correlations’ possible dependency on topography and hypnotizability in these states. The present study
describes the results of fractal analysis of subjects’ EEGs, recorded during auditory stimulation in the hypnotic and waking states with respect to their topography and hypnotizability.

**METHOD**

**Subjects**

This study recruited 10 medically healthy, volunteer university students through advertisements. To exclude those with psychiatric symptoms, we conducted clinical interviews with the subjects and administered the Beck Depression Inventory (BDI) and State-Trait Anxiety Inventory (STAI) to them. In addition, we measured their hypnotizability via the Hypnotic Induction Profile (HIP), Dissociative Experience Scale (DES), and Tellegen Absorption Scale (TAS).

**Instruments**

The HIP is a standardized tool that produces both quantitative and qualitative hypnotizability scores (Gritzalis, Oster, & Frischholz, 2009; Stern, Spiegel, & Nee, 1978). The quantitative scores are the induction score and the Eye-Roll Sign, and the qualitative score is the profile score (H. Spiegel & Spiegel, 1978, 2004). The induction score (0–10) comprises five items, each scored on a 0–2 scale: reported hand dissociation, levitation of the hand after it has been put down, sense of involuntariness during the levitation, response to the cutoff signal ending hypnotic alteration of control, and sensory alteration involving floating, lightness, or buoyancy. The Eye-Roll Sign is measured on a 0–4 scale, based upon the subject’s ability to maintain an upward gaze while lowering the eyelids. The profile score has a nominal scale. It describes the subject’s hypnotic response pattern and represents the actually experienced trance level in relation to the Eye-Roll Sign score. This study used the standardized Korean version of the HIP (HIP–K; Pyun, 1987). Young-don Pyun, a board-certified Diplomate of The American Board of Medical Hypnosis, translated the original HIP into the Korean language, and then Nam-Hee Won, a certified English teacher, back-translated it into English. They sent this to David Spiegel, MD, the HIP’s original author, and, after several corrections, completed the Korean version of the HIP with David Spiegel’s permission.

We administered the DES and TAS to measure the subjects’ subjective relaxation scores. The DES is a self-report scale, comprising 28 questions, which quantifies the dissociation state. This study used the standardized Korean version of the Dissociation Experience Scale (DES–K; J. M. Park et al., 1995). The TAS is a questionnaire, comprising 34 questions, which measures the subject’s ability to become absorbed...
in the object of attention. This study used the standardized Korean version of the Tellegen Absorption Scale (TAS–K; H. K. Park, Lee, Son, Shin, & Kim, 1998).

Psychiatrist J. S. Lee, an author of this study, previously participated in the hypnotherapy workshop of Herbert Spiegel and David Spiegel in New York and learned the HIP. He has extensive experience with hypnosis and the HIP, and he administered all three instruments to the subjects. All subjects were right-handed, 3 of them were female, and 7 were male. All were medically healthy, with no history of alcohol or drug abuse, head trauma, epileptic episodes, or other systemic diseases that might affect brain function. The subjects’ average age was 24 ($SD = 7.9$), their mean induction score was 6.8 ($SD = 2.67$), and their mean Eye-Roll Sign score was 2.6 ($SD = 0.98$; Table 1). No subjects in this study had Soft and Decrement. Their mean DES score was 21.9 ($SD = 20.0$), and their mean TAS score was 54.4 ($SD = 9.1$).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female$^a$</td>
<td>3</td>
<td>30%</td>
</tr>
<tr>
<td>Age</td>
<td>24</td>
<td>7.9</td>
</tr>
<tr>
<td>HIP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Up-gaze</td>
<td>2.4</td>
<td>0.74</td>
</tr>
<tr>
<td>Eye-roll sign</td>
<td>2.6</td>
<td>0.98</td>
</tr>
<tr>
<td>Arm levitation instruction</td>
<td>2.2</td>
<td>1.33</td>
</tr>
<tr>
<td>Tingle</td>
<td>1.6</td>
<td>0.84</td>
</tr>
<tr>
<td>Dissociation</td>
<td>1.3</td>
<td>0.92</td>
</tr>
<tr>
<td>Postinduction levitation</td>
<td>1.0</td>
<td>0.71</td>
</tr>
<tr>
<td>Control differential</td>
<td>1.6</td>
<td>0.70</td>
</tr>
<tr>
<td>Cutoff</td>
<td>1.6</td>
<td>0.70</td>
</tr>
<tr>
<td>Amnesia to cutoff</td>
<td>1.8</td>
<td>0.63</td>
</tr>
<tr>
<td>Floating sensation</td>
<td>1.3</td>
<td>0.67</td>
</tr>
<tr>
<td>Induction score</td>
<td>6.8</td>
<td>2.67</td>
</tr>
<tr>
<td>DES</td>
<td>21.9</td>
<td>20.0</td>
</tr>
<tr>
<td>TAS</td>
<td>54.4</td>
<td>9.1</td>
</tr>
<tr>
<td>BDI</td>
<td>5.4</td>
<td>3.9</td>
</tr>
<tr>
<td>STAI–S</td>
<td>40.6</td>
<td>4.5</td>
</tr>
<tr>
<td>STAI–T</td>
<td>41.5</td>
<td>5.1</td>
</tr>
</tbody>
</table>

*Note.* HIP = Hypnotic Induction Profile; DES = Dissociation Experiences Scale; TAS = Tellegen Absorption Scale; BDI = Beck Depression Inventory; STAI–S = State–Trait Anxiety Inventory–State; STAI–T = State–Trait Anxiety Inventory–Trait.

$^a$In n and percentage.
Procedure

First, we showed the subjects the hypnosis setting, including EEG equipment, and explained the procedure. Then, each subject was seated on a comfortable armchair in a sound-attenuated, dimly lit, quiet room and electrodes were attached to him or her. After they had become accustomed to the setting, we checked the subjects by collecting a 5-minute resting EEG with eyes closed. A hypnotist sat beside each subject and performed hypnosis using a modified HIP technique, containing only the Eye-Roll and Instructional Arm Levitation.

The hypnosis comprised four stages: (Stage 1) quiet wakefulness (a relaxed state with eyes closed); (Stage 2) beginning hypnotic induction; (Stage 3) hypnotic condition (hypnotized state with eyes closed); and (Stage 4) end of hypnotic condition (with a suggestion of wakening and eye opening). During these periods (except for Stage 4), the subject was told to keep their eyes closed. The mean total EEG recording (including Stages 1, 2, 3, and 4) duration was approximately 38 minutes, and the mean hypnotic condition duration (Stage 3) was 21 minutes. We used Stage 1 (waking) and Stage 3 (hypnosis) data in this analysis. During the measurement tests, we asked the subjects to listen, for 5 minutes at a time, to sounds at different decibels. For one condition, we asked subjects to listen to the sounds for 5 minutes in the waking state (no hypnosis) while focusing on (selecting) the sounds having different decibels. In the second condition, we asked them to listen to the sounds while disregarding (ignoring) the differing decibels. For the third and fourth conditions, we gave the same instructions, but for the hypnosis condition. We recorded each subject’s EEG for each condition and analyzed the subjects’ EEGs as measured during the first 3 minutes of each 5-minute increment. The EEG data set totaled 40 (each of four conditions for each of 10 volunteers).

EEG Recordings

We recorded the EEG data on a Telefactor EEG-monitoring device in the EEG recording room. To avoid disturbances and interference, the recording room was shielded with copper. The EEGs were recorded with silver-silver chloride cup electrodes (Ag-AgCl), attached by means of collodion, on the F3 and F4 (frontal), C3 and C4 (central), T3 and T4 (temporal), and O1 and O2 (occipital) scalp regions of the 10–20 international system (American Electroencephalographic Society, 1994). All electrode impedances were below 5 kΩ. The EEG-measurement-device (LEX3208, LAXTHA Inc., Korea) settings were as follows: 256 Hz sampling rate, 12-bit analog-to-digital (A/D) converter, 0.6 Hz high-pass filter, 46 Hz low-pass filter, and 60 Hz notch filter. We visually inspected the EEG recordings for artifacts and discarded data contaminated with artifacts.
Through both sides of their headphones, the subjects heard low-pitched tones of 1000 Hz (S1) randomly mixed with high-pitched tones of 2000 Hz (S2). The auditory stimulation frequency was 1 per 3 seconds, and the stimulation intensity was 70 dB. The subjects were stimulated 100 times in each state, and the S1 to S2 ratio was 1:1. Stimulus duration was 40 msec (Roth & Cannon, 1972).

Scaling Exponents and Detrended Fluctuation Analysis

We analyzed the EEG data collected in the hypnotic and resting wakeful states using the DFA method. DFA is a fractal analysis method for quantifying the correlation property in a nonstationary time series, by computing a scaling exponent via a modified root mean square analysis of a random walk. Previous researchers have described the implementation of the DFA algorithm of scaling exponent in detail (Peng et al., 1993, 1995).

The normal scaling exponent range is 0.5–1.5. According to the signal characteristics, a scaling exponent of 0.5 is white noise, a state in which the current value does not correlate with the previous one at all. In other words, it indicates a signal with no correlation on the time axis, where the autocorrelation coefficient becomes zero. A scaling exponent of 1.0 is called “1/f noise,” “flicker noise,” or “pink noise.” A scaling exponent of 1.5 is Brownian noise, a random movement like that of a particle in Brownian motion, or the continuous sum of independent observations expressed as a random walk process. In a random walk, the interval between steps is random, but the addition of some value to the current position determines the value of the next position (Peng et al., 1995). In the case of a scaling exponent greater than 0.5 and less than 1.0, the scaling exponent represents a continuous, long-term correlation. Finally, if the scaling exponent is greater than 1, there is a correlation with the original signal (not integrated), but it does not take the power-law form (Peng, Hausdorff, & Goldberger, 2000). The scaling exponent is the focus of this study.

Although DFA is the optimal fractal analysis method for finding an EEG’s general long-term trend, extracting results from a case takes 25–48 hours, a possible shortcoming when one requires a long analysis, as in over 10 minutes of hypnosis EEG analysis. To compensate for this, we applied Gotman’s wave-simplifying method (Gotman, 1990), and this technique successfully reduced the amount of analyzed data to 20% of the original data’s amount (for more details, see J. S. Lee, Spiegel, et al., 2007).

Statistical Analysis

We performed Pearson correlation analyses to evaluate correlations among the HIP, DES, and TAS scores and the EEG scaling exponents...
and performed a repeated-measured analysis of variance (ANOVA) to compare with ignoring tone and selecting tone between hypnotic and waking states. All statistical procedures were performed using SPSS 10 for Windows. Statistical significance was set at $\alpha = .05$ for these analyses.

**Results**

*EEG Scaling Exponents From Fractal Analyses of the Perception of Ignored and Selected Tones During Waking and Hypnosis*

Table 2 shows the means and standard deviations of the EEG scaling exponents at each channel and for each auditory stimulation condition during the waking and hypnotic states. The DFA values from when the subjects listened to sounds while focusing on the different decibels (selecting condition) were lower than the ones from when the subjects disregarded the different decibels (ignoring condition). In addition, the DFA values from subjects in the hypnotic state were lower than the ones from subjects in the waking state.

*Correlations Between the Subjects’ HIP, DES, and TAS Results.* As shown in Table 3, several of the HIP items, including the Eye-Roll Sign and Up-Gaze, showed positive correlations with one another. However, the DES and TAS showed a negative correlation with each other and no significant correlations with any HIP items.

<table>
<thead>
<tr>
<th>Condition</th>
<th>No hypnosis (Waking)</th>
<th>Hypnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ignoring Tones</td>
<td>Selecting Tones</td>
</tr>
<tr>
<td>F3</td>
<td>Mean 0.85 SD 0.21</td>
<td>Mean 0.73 SD 0.14</td>
</tr>
<tr>
<td>F4</td>
<td>Mean 0.83 SD 0.26</td>
<td>Mean 0.74 SD 0.15</td>
</tr>
<tr>
<td>C3</td>
<td>Mean 0.82 SD 0.26</td>
<td>Mean 0.71 SD 0.17</td>
</tr>
<tr>
<td>C4</td>
<td>Mean 0.81 SD 0.23</td>
<td>Mean 0.71 SD 0.16</td>
</tr>
<tr>
<td>T3</td>
<td>Mean 0.87 SD 0.23</td>
<td>Mean 0.75 SD 0.19</td>
</tr>
<tr>
<td>T4</td>
<td>Mean 0.91 SD 0.27</td>
<td>Mean 0.81 SD 0.17</td>
</tr>
<tr>
<td>O1</td>
<td>Mean 0.88 SD 0.29</td>
<td>Mean 0.76 SD 0.23</td>
</tr>
<tr>
<td>O2</td>
<td>Mean 0.90 SD 0.32</td>
<td>Mean 0.78 SD 0.24</td>
</tr>
</tbody>
</table>

Table 2

*EEG Scaling Exponents From Fractal Analyses in Subjects Instructed to Ignore or Select the Different Tones During the No Hypnosis (Waking) and Hypnosis Conditions*
Table 3

Correlations Among the Subjects’ HIP, DES, and TAS Results

<table>
<thead>
<tr>
<th>HIP</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Up-Gaze</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2. Eye-Roll Sign</td>
<td>.89**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Arm Levitation Instruction</td>
<td>.27</td>
<td>.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Tingle</td>
<td>.29</td>
<td>.29</td>
<td>−.14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Dissociation</td>
<td>.33</td>
<td>.38</td>
<td>.12</td>
<td>.72*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Postinduction Levitation</td>
<td>.32</td>
<td>.24</td>
<td>.53</td>
<td>.37</td>
<td>.34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Control Differential</td>
<td>−.09</td>
<td>−.29</td>
<td>.61</td>
<td>.08</td>
<td>−.09</td>
<td>.34</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>8. Cutoff</td>
<td>−.09</td>
<td>−.29</td>
<td>.43</td>
<td>.45</td>
<td>.17</td>
<td>67*</td>
<td>.77*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Amnesia to Cutoff</td>
<td>−.29</td>
<td>−.52</td>
<td>.57</td>
<td>−.17</td>
<td>−.29</td>
<td>.50</td>
<td>.80**</td>
<td>.80**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Floating Sensation</td>
<td>.40</td>
<td>.31</td>
<td>.31</td>
<td>.63</td>
<td>.58</td>
<td>.35</td>
<td>.52</td>
<td>.52</td>
<td>.16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Induction Score</td>
<td>.25</td>
<td>.12</td>
<td>.53</td>
<td>.64*</td>
<td>.61</td>
<td>.74*</td>
<td>.66*</td>
<td>.83**</td>
<td>.50</td>
<td>.82**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. DES</td>
<td>.19</td>
<td>.02</td>
<td>.29</td>
<td>.27</td>
<td>.19</td>
<td>.12</td>
<td>.23</td>
<td>.12</td>
<td>−.05</td>
<td>.28</td>
<td>.26</td>
<td></td>
</tr>
<tr>
<td>13. TAS</td>
<td>−.29</td>
<td>−.08</td>
<td>−.50</td>
<td>−.24</td>
<td>−.03</td>
<td>−.29</td>
<td>−.50</td>
<td>−.34</td>
<td>−.22</td>
<td>−.44</td>
<td>−.41</td>
<td>−.90**</td>
</tr>
</tbody>
</table>

Note. HIP = Hypnotic Induction Profile ; DES = Dissociation Experiences Scale ; TAS = Tellegen Absorption Scale.

*p < .05. **p < .01.
HIP-induction score showed a positive correlation with the Eye-Roll Sign. Furthermore, the HIP-induction score, Eye-Roll Sign, and subjective relaxation all showed high positive correlations with one another. This suggests empirical support for the idea that these scales do assess hypnotizability and relaxation. There were no significant correlations between gender or age and any scale that assessed hypnotizability or relaxation (data not shown).

**Correlations Between the Reduced EEG Scaling Exponents for F3 and C3 From Fractal Analyses in the Ignoring Tones (Waking and Hypnosis) Condition and the Subjects’ Hypnotizability.** Table 4 shows the correlations between the F3 and C3 EEG scaling exponents from fractal analyses in the ignoring tones (during waking and hypnotic states) condition and hypnotizability. The different DFA value (waking and hypnosis) for F3 showed a significant negative correlation with the HIP’s cutoff and amnesia items. However, we found no correlations with the other HIP indexes, the DES, or the TAS. The different DFA value (waking and hypnosis) for C3 showed a significant positive correlation with the HIP Eye-Roll Sign. However, we found no correlation with the other HIP indexes, the DES, or the TAS.

**At F3 and C3, Instruction to Ignore Perceived Tones Resulted in a Significant Reduction of the EEG Scaling Exponents From Fractal Analyses**

<table>
<thead>
<tr>
<th></th>
<th>F3</th>
<th>C3</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Up-Gaze</td>
<td>.52</td>
<td>.58</td>
</tr>
<tr>
<td>Eye-Roll Sign</td>
<td>.54</td>
<td>.67*</td>
</tr>
<tr>
<td>Arm Levitation Instruction</td>
<td>−.05</td>
<td>.13</td>
</tr>
<tr>
<td>Tingle</td>
<td>−.04</td>
<td>.32</td>
</tr>
<tr>
<td>Dissociation</td>
<td>.337</td>
<td>.51</td>
</tr>
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<td>Postinduction Levitation</td>
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<tr>
<td>Control Differential</td>
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<td>−.25</td>
</tr>
<tr>
<td>Cutoff</td>
<td>−.67*</td>
<td>−.35</td>
</tr>
<tr>
<td>Amnesia to Cutoff</td>
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<td>−.59</td>
</tr>
<tr>
<td>Floating Sensation</td>
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<td>.21</td>
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<tr>
<td>Induction Score</td>
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<td>.02</td>
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<tr>
<td>DES</td>
<td>.21</td>
<td>.01</td>
</tr>
<tr>
<td>TAS</td>
<td>−.01</td>
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*Note. HIP = Hypnotic Induction Profile; DES = Dissociation Experiences Scale; TAS = Tellegen Absorption Scale. *p < .05.
in the Hypnotic as Compared to Waking State. Figure 1 shows the differences between the DFA values for the waking and hypnotic states, at each EEG channel, under auditory stimulation. In the areas of F3 and C3, we found a considerable difference in the DFA values between two different states—the waking state and the hypnotic state—when subjects received the order to disregard (ignore) the tones’ differing decibels.

**Discussion**

This study tested neurophysiological differences in waking and hypnotic states by analyzing EEG data in response to auditory stimuli via DFA and by examining the associations between EEG and hypnotizability and each state’s topographical characteristics.

First, the scaling exponents, which are the DFA values produced when subjects heard a sound in the waking or hypnotic states, were all between 0.5 and 1.0. In particular, the fact that the EEG scaling exponent during the waking-state eye closure was 0.5–1.0, which is similar to previously reports, indicates the brain waves had the typical $1/f$ noise value and long-range power-law correlations. Further, we observed a significant effect between the waking and hypnotic states. While the scaling exponents during the hypnotic state were closer to that of white noise (scaling exponent = 0.5), those of the waking state were closer to that of $1/f$ noise (scaling exponent = 1.0). These results imply that specific mechanisms related to the generation of the hypnotic neuronal process might affect these scaling exponents. This finding shows the fractal dynamics of EEG rhythm are more random and less correlated in the hypnotic than in the waking state and supports the validity of the data and analyses in this study (Jiang et al., 2005; J. S. Lee, Spiegel, et al., 2007).

The scaling exponent was closer to 0.5 when waking state subjects selected the different perceived tones than it was when they ignored the perceived tones. In the hypnotic state, the scaling exponent was closer to 0.5 when the subjects selected the perceived tones than it was when they ignored the perceived tones. Ultimately, the scaling exponent was closest to 0.5 when the subjects selected perceived tones in the hypnotic state. This suggests that when a person hears a sound while concentrating, that is, when the brain concentrates, the brain waves have differing chaotic natures in the waking state and the hypnotic state. This is consistent with the report of Jiang et al. (2005) that the scaling exponent differed according to the mental task.

Previous studies showed the sleep EEG scaling exponent was closer to Brownian noise (scaling exponent = 1.5) as the brain went into deep sleep (J. M. Lee et al., 2002), which contrasts with the hypnotic state, and that the scaling exponent was closer to 1 in those with dementia.
Figure 1. At F3 (*p < .05) and C3 (**p < .01), the instruction to ignore perceived tones resulted in a significant reduction of the EEG scaling exponents from fractal analyses in the hypnosis compared to the waking conditions.
or depression than in controls (Abásolo, Hornero, Escudero, & Espino, 2008; J. S. Lee, Yang, et al., 2007). In addition, Babloyantz and Destexhe (1986), who compared EEGs between epilepsy patients and a control group, reported controls’ EEGs showed more chaotic characteristics than did those of epilepsy patients, explaining that this occurred because epilepsy patients had lost the brain’s electrical-signal diversity. Moreover, Parish et al. (2004) reported that the temporal correlation decay of the epileptogenic hippocampus occurred more slowly than did that of the nonepileptogenic hippocampus, and this electrophysiologic evidence suggests the epileptogenic hippocampus possesses different underlying neuronal dynamics.

Spiegel explains that hypnosis is a state of weakened peripheral consciousness and strengthened focal consciousness (D. Spiegel, 1991). On this basis, hypnosis can be considered a kind of high-degree concentration. The scaling exponent is closer to 0.5 in high-degree concentration, such as perceiving a selected tone in a hypnotic state, and it is closer to or exceeds 1 in a nonhypnotic waking or sleep state and in a pathologic state, such as depression or dementia. This suggests brain waves’ fractal dynamics during hypnosis or high-degree concentration is more random and less correlated than are those in a nonhypnotic waking state or a pathologic state (J. S. Lee, Spiegel, et al., 2007). Moreover, it suggests underlying neuronal dynamics may differ between the waking and hypnotic states and between states with and without concentration.

When subjects do not concentrate, that is, when the scaling exponents are closer to 1, W. J. Freeman suggests it is priming to receive stimuli, and the brain’s normal background activity is more chaotic (W. J. Freeman, 1987). Rapp et al. (1989) supported Freeman’s theory, suggesting the fractal dimension is higher when one hears a sound without concentration and that this state is ready to hear the sound. Moreover, Linkenkaer-Hansen et al. (2004), who observed changes in EEGs’ long-range temporal correlations and power-law scaling by using somatosensory stimuli, reported that, upon somatosensory stimulus application, long-range temporal correlation and power-law scaling behavior continued, but the magnitudes of the temporal correlation and power-law exponent diminished. This is similar to the result in this study, in which subjects received auditory stimuli in the waking and hypnotic states. We saw degradation of the hypnotic state EEGs’ long-range correlation as compared to the waking state. This suggests a loss of normal patterns of integrated physiological responsiveness. The most highly correlated brain activity patterns appear in deep sleep or psychiatric disorders, such as depression and dementia. A state close to white noise implies the local neural activity patterns are highly independent, and the dissociation of centralized activity occurs with a hypnotic state (J. S. Lee, Spiegel, et al., 2007).
Regarding correlations among the DES, TAS, and HIP, several HIP items, including the Eye-Roll Sign and Up-Gaze, showed high correlations with one another. In addition, we observed a high correlation between the DES and TAS, but neither correlated with any of the HIP items. This means that, although the DES and TAS can measure the degree of dissociation or absorption, they have no direct association with the degree of hypnosis, that is, hypnotizability. Previous researches also have shown no relationship between hypnotic susceptibility and dissociation (DiTomasso & Routh, 1993; Green, 1997). At F3 and C3, the scaling exponent of the difference between the waking and hypnotic states when subjects ignored the tones correlated significantly with some HIP items but not with the DES or TAS. This shows the HIP at least reflects the neurophysiological characteristics of hypnosis better than the DES and TAS do. Among the HIP items, the Eye-Roll Sign showed a high correlation with Up-Gaze, but, in nonlinear analyses of actual EEGs, we observed a significant correlation between brain waves and the Eye-Roll Sign. This suggests that, as Spiegel reported earlier, the Eye-Roll Sign reflects the neurophysiological characteristics of hypnosis, making it the neurophysiological marker correlating most closely with hypnotizability. Spiegel said the hypnosis phenomenon involves three elements: absorption, dissociation, and suggestibility (D. Spiegel, 1991). Because the DES and TAS measure only dissociation and absorption, the HIP is the most useful tool, as it measures hypnotizability by including all three elements.

The C3 region showed a correlation with the Eye-Roll Sign. This region, a central area, belongs to the frontal eye fields (FEF), so it contributes to eye movements (Blumenfeld, 2002). Rosano, Sweeney, Melchitzky, and Lewis (2003) reported this region activates during the performance of oculomotor tasks, and such monitoring of eye movements is critical for spatial attention and visual perception. Furthermore, the positive correlation between the Eye-Roll Sign and the C3 region’s DFA value means the higher the score on the Eye-Roll Sign, the greater the difference in the C3 DFA value between the waking and hypnotic states in the ignoring tone condition. This in turn means that, at C3, the hypnotic state’s neurophysiological characteristics differ according to the degree of the Eye-Roll Sign. That is, the hypnotic condition’s degree deepens as the Eye-Roll Sign score increases. Therefore, we can say the Eye-Roll Sign predicts the DFA value of the EEG characteristic according to the degree of hypnosis.

Among the HIP items, F3’s DFA value showed a negative correlation with cutoff and amnesia to cutoff. The F3 area belongs to the FEF and is also associated with the attentional process (Blumenfeld, 2002). Among the HIP items, cutoff and amnesia to cutoff showed high correlations with each other. If cutoff is high, the subject recovers from hypnosis.
more easily, and if amnesia to cutoff is high, the subject remembers more poorly after recovery from hypnosis. Accordingly, the negative correlation between these two values and F3 means the hypnotic state and the degree of concentration in F3 change according to cutoff and amnesia to cutoff. However, more specific studies are needed in the future.

Differences in attention can explain individuals’ differences regarding their depth of hypnosis and hypnotizability. Moreover, changes in the stimuli perception cause variations in the allocation of attentional resources (De Pascalis, 1999). Researchers have long suggested that the cognitive and behavioral phenomena related to hypnosis associate mainly with the attentional process. In addition, individual differences in hypnotizability are associated with the frontal attention system’s efficiency (Egner, Jamieson, & Gruzelier, 2005). Therefore, changes in the F3 region presumably reflect changes in the degree of the hypnotic or attentional state.

As shown in Figure 1, the brain waves at F3 and C3 showed a significant difference in DFA values between the waking and hypnotic states. According to Spiegel, the nature of the specific hypnotic instruction determines the hypnotic alteration of perception, and regions this alteration activates show changes mainly in perceptual and attentional functions (D. Spiegel, 2003). Therefore, F3 and C3, regions associated with attention and perception, are presumably involved. That is, the fact that, when subjects ignored the tones, the changes in the scaling exponents between the hypnotic and waking states were greater than they were when subjects selected the tones suggests the change is greater when subjects do not concentrate than when they do. It also suggests the neurophysiological mechanism in the absence of concentration differs from that with concentration.

In the past, research on brain laterality related to the hypnosis phenomenon presumed the phenomenon would associate mainly with the right hemisphere (Mészáros & Szabó, 1999). This originates from the idea that the right hemisphere might be involved in imaginative, holistic, or oppositional thinking (Jasiukaitis, Nouriani, Hugdahl, & Spiegel, 1997). However, little evidence has shown hypnosis connects directly to the right hemisphere. Moreover, some researchers insist it associates with the left hemisphere. This arises mainly from experiences with suggestion via language, data collected from the surrounding environment through the medium of perception, and stored memories, and such hypnosis requires narrowing and/or fractionating one’s awareness. That is, because attentional focusing or concentration and the translation or acceptance of verbal content (hypnotic commands) are essential factors in hypnosis, the left hemisphere’s involvement is important (Jasiukaitis et al., 1997; Maquet et al., 1999). According to recent neuroimaging studies, subtle neuronal activation changes
appear during hypnotic suggestion, particularly in the left hemisphere (Kosslyn, Thompson, Costantini-Ferrando, Alpert, & Spiegel, 2000; Rainville et al., 1999). In this study, we also assumed auditory stimuli, which arrived from the surrounding environment through the medium of perception in the waking and hypnotic states, caused changes in attentional resources and, therefore, we observed the changes mainly in the left hemisphere.

This study’s limitations are the small number of subjects and the eight-channel EEG electrodes we used. Thus, further research, with a larger subject group, using multichannel electrodes, is required. To sum up, we suggest the application of auditory stimuli in hypnotic and waking states is useful for understanding the neurophysiological characteristics of hypnosis and hypnotizability in the nonlinear analysis of brain waves.

References


Fraktalanalyse von EEGs auf auditive Stimulation während des Wachzustandes und während Hypnose bei gesunden Freiwilligen

Jun-Seok Lee und Bon-Hoon Koo


Stephanie Reigel, MD

L’analyse fractale de l’EEG durant une stimulation auditive en état de veille ou en état d’hypnose chez des volontaires en bonne santé

Jun-Seok Lee et Bon-Hoon Koo

Résumé: Les auteurs ont testé l’Analyse de fluctuation dissociative (DFA) d’EEG en relation avec la topique et l’hypnotisabilité, à la suite d’une stimulation auditive à l’état conscient ou en état hypnotique. Ils ont administré à 10 volontaires en santé les questionnaires Profil d’induction hypnotique (HIP), Échelle d’expériences dissociatives et Échelle d’absorption de Tellegen, et ont mesuré les EEG de ces sujets pendant que ceux-ci écoutaient des sons, tout en sélectionnant ou en ignorant la différence du nombre de décibels de ceux-ci, en état de veille ou en état d’hypnose. Les composantes statistiques graduées de l’échelle de la DFA étaient les plus près de 0,5 lorsque les sujets percevaient les tons en état d’hypnose. Différentes valeurs de DFA au point C3 ont montré des corrélations positives significatives avec le roulement des yeux mesuré selon le HIP. Les valeurs
de la DFA aux points F3 et C3 indiquaient une différence significative entre l’état de veille et l’état hypnotique, donnant ainsi du poids à la documentation appuyant la théorie de l’état d’hypnose. L’application de stimuli auditifs est utile pour comprendre les caractéristiques neurophysiologiques de l’hypnose à l’aide de la DFA.

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Análisis Fractal del EEG durante estimulación auditiva en vigilia e hipnosis en voluntarios saludables

Jun-Seok Lee y Bon-Hoon Koo

Resumen: Los autores evaluaron análisis de fluctuación (DFA) de EEGs durante una estimulación auditiva en estados de vigilia e hipnótico en relación a topografía e hipnotizabilidad. Administraron el Perfil de Inducción Hipnótica (HIP), la Escala de Experiencias Disociativas, y la Escala de Absorción de Tellegen a 10 voluntarios sanos y midieron los EEGs de los sujetos mientras escuchaban sonidos, ya sea seleccionando o ignorando tonos de distintos decibeles, en estado de vigilia o hipnótico. Los exponentes de escala DFA se acercaron más a 0.5 cuando los sujetos reportaron los tonos en estado hipnótico. Distintos valores DFA en C3 mostraron correlaciones positivas significativas con la señal para levantar los ojos del HIP. Contribuyendo a la literatura que sustenta la teoría de estado de la hipnosis, los valores DFA en F3 y C3 mostraron diferencias significativas entre los estados de vigilia e hipnótico. La aplicación de estímulos auditivos es útil en el entendimiento de las características neurofisiológicas de la hipnosis utilizando DFA.

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