

## SPECIAL ISSUE

# Ultradian and Circadian Effects in Electroencephalography Activity

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*Circadian effects in human electroencephalography (EEG) have been studied for decades, although less is known about ultradian effects (less than a day). EEG spectral activity was examined across a 12-hour time period for semicircadian and ultradian influences in 130 individuals. Analysis was performed on spectral magnitudes of six narrow-frequency bands from 3 to 15 Hz. A maximum peak of activity in all frequencies was observed around 1 p.m., which is consistent with previous findings. Local maxima (peaks) also occurred every 2 hours or so in parietal activity, which would fit the literature's basic rest-activity cycle.*

Circadian effects in human electroencephalography (EEG) were identified nearly 40 years ago (Scheich, 1969), and since then, more than a dozen studies have been published on homeostatic regulation of EEG (e.g., Gertz & Lavie, 1983; Gundel & Hilbig, 1983; Hayashi, Sato, & Hori, 1994; Manseau & Broughton, 1984; Meneses Ortega & Corsi Cabrera, 1990; Tsuji & Kobayashi, 1988). Recently, Cummings, Dane, Rhodes, Lynch, and Hughes (2000) reported a prominent circadian rhythm influencing theta, lower alpha, and lower beta activity. Likewise, Chapotot, Jouny, Muzet, Buguet, and Brandenberger (2000) reported significant periodicities of most frequency bands, ultradian and circadian in nature.

Extensive neurophysiological research indicates thalamocortical generation of EEG rhythms (e.g., Steriade, 2003). The intrinsic properties of thalamic relay neurons, local excitatory modulation, inhibitory inputs, and cortical excitability all contribute to the generation of measurable EEG periodicity (McCormick & Bal, 1997; Steriade & Llinás, 1988), and among other factors, the amplitude of such rhythms depends in part on homeostatic influences. Theta activity, for instance, peaks shortly after the onset of melatonin secretion, and high alpha activity is minimal when body temperature is minimal (Aeschbach et al., 1999).

In the course of conducting numerous EEG studies, the Sterman-Kaiser Imaging Laboratory has amassed a substantial amount of 19-channel EEG data during eyes-closed and eyes-open baseline conditions at different times throughout the waking day. It was thus possible to examine EEG across a

12-hour time period and to evaluate ultradian influences on the neural substrates of EEG rhythm generation.

## Method

### Participants

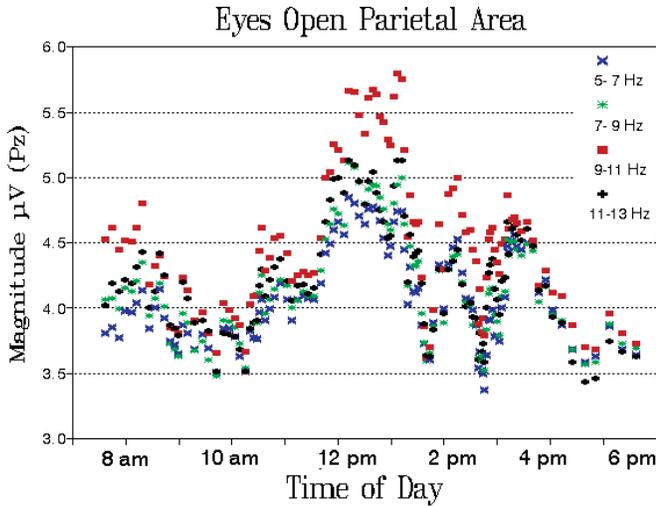
EEG was acquired from 130 healthy right-handed adults between the ages of 19 to 43 years (mean of 32 years; 20 females, 110 males). Participants underwent eyes-closed and -open baseline and task conditions. Handedness was determined by a modified Edinburgh Handedness Inventory (Oldfield, 1971) and confirmed by writing samples from each hand. Participants reported no history of neurological disorder, no use of a controlled substance 24 hours prior to the study, and no recent experiences that could be expected to alter psychophysiology (e.g., disturbed sleeping habits, atypical stress). Participants were recruited from the University of California, Los Angeles, and California State University, Northridge, and informed consent was obtained from each adult prior to his or her participation using a form approved by a Veterans' Administration Human Study Committee.

### Materials

EEG was recorded with a Neurosearch-24 (Lexicor Medical Technologies, Inc., Augusta, GA) using 12-bit A/D and digitized at 512 samples per second, down-sampled and displayed 128 times per second. High- and low-pass filters were set at 1.5 Hz and 38 Hz, with rolloffs of 12 and 48 dB per octave, respectively. The common mode rejection ratio was 90 dB at 60 Hz, with notch filtering at 60 Hz. Topographic EEG was recorded from scalp referenced to linked ears using sized elastic lycra caps (Electro-Cap International Inc., Eaton, OH) of 20 electrode ports arranged by the International 10-20 electrode placement system.

### Procedure

EEG was acquired at Sepulveda Veterans Administration Medical Center Neuropsychology Laboratory. Participants were tested individually in a dimly lit electrically shielded and sound-attenuated room. Electrode impedances were kept below 5 K Ohms. Eyes-closed baseline conditions of 2

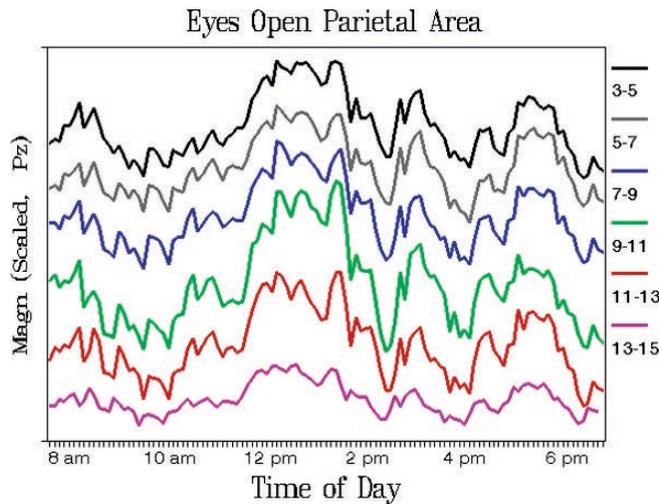


**Figure 1.** Smoothed scatterplot (20 individuals per point) showing the distribution of electroencephalography spectral magnitudes in four 2-Hz frequency bands from 130 subjects recorded during a standardized eyes-open control condition at different times between 8 a.m. and 8 p.m. The data shown here are from the midparietal area (Pz). Sponsorship for color figures provided by BrainMaster Technologies, Inc.

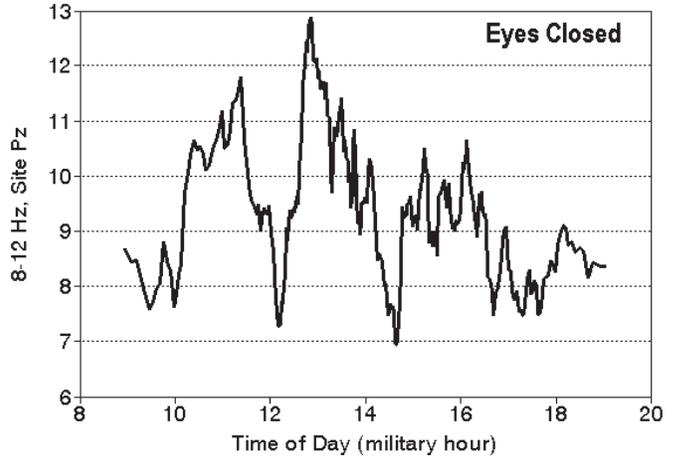
minutes or longer were recorded twice, spaced apart by 30 to 60 minutes.

**Data Analysis**

EEG records were inspected for artifacts, and contaminated segments were eliminated prior to spectral analysis. If an artifact was present in any channel, spectral coefficients from all 19 recording channels were ignored for its duration. As little as a 100-ms segment could be eliminated in this fashion. Only eyes-closed baseline recordings were analyzed, and values represented averages of replicated recordings from each



**Figure 2.** Smoothed scatterplot of electroencephalography magnitudes in six 2-Hz frequency bands (3–15 Hz) at recording site Pz from 130 subjects recorded during an eyes-open baseline condition. Sponsorship for color figures provided by BrainMaster Technologies, Inc.

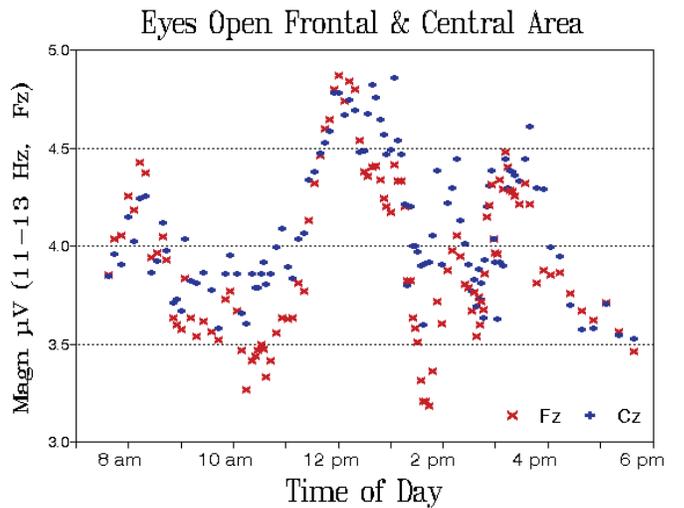


**Figure 3.** Smoothed scatterplot showing the distribution of midparietal alpha magnitudes (8–12 Hz) from 130 subjects recorded during an eyes-closed baseline condition. Data are less smoothed than previous graphs (five individuals per point).

participant. Digitized signals underwent cosine tapering using a Blackman-Harris four-term function with 75% data window overlap, which produces equal representation of all signals in both time and frequency domains (Kaiser & Serman, 2001). Analysis was performed on a spectral magnitude of six 2-Hz frequency bands from 3 to 15 Hz. An analysis of variance and sequential planned comparison tests were performed to determine the statistical significance of this modulation.

**Results**

Main effects and interactions of site, frequency, and time of day (based on 2-hour intervals) were significant ( $p < .05$ ). Spectral activity modulated across the day in all frequencies and sites, with a dominant peak around 1 p.m. An analysis of



**Figure 4.** Smoothed scatterplot showing the distribution of electroencephalography magnitudes in the 11- to 13-Hz frequency band at recording sites Fz and Cz, respectively, from 130 subjects recorded during eyes-open control. Sponsorship for color figures provided by BrainMaster Technologies, Inc.

this modulation in the parietal area confirmed a significant trough around 10 a.m. and a peak before 2 p.m. in all frequency bands ( $p < .05$ ), as shown in Figures 1 and 2. Visual inspection of these data suggests an additional weaker modulation with a cycle of approximately 120 minutes, clearly shown in Figure 3, and present in other topographic areas as well (see Figure 4).

## DISCUSSION

Spectral magnitudes during rest conditions modulated throughout the day, from 9 a.m. to 7 p.m. This modulation was consistent across a broad frequency range, as was reported by Chapotot et al. (2000) and others. Rhythmic activity was reliably suppressed during mid-morning and early evening hours and increased shortly after noon.

The fact that EEG rhythms modulated across the day suggests that there exist influences that organize cortical expression of thalamic input. The general temporal pattern—attenuation in mid-morning and early evening and enhancement at mid-day—is consistent with the human sleep-wake cycle. Sleep latencies typically increase at the beginning and end of the day, with the shortest sleep latencies at mid-day (Mitler & Miller, 1996; Roehrs & Roth, 1992). The ultradian rhythms observed in the EEG approximated the Basic-Rest-Activity-Cycle of Kleitman (1963) and may reflect a waking manifestation of 90 to 120 minutes of REM/NREM periods of sleep (Aeschbach et al., 1997).

Especially relevant to the field of neurotherapy is the possibility that EEG activity may be a function of both operant conditioning and homeostatic variation. Gertz and Lavie (1983) published “Biological Rhythms in Arousal Indices: A Potential Confounding Effect in EEG Biofeedback,” in which they analyzed EEG from 11 individuals for approximately 8 hours. Arousal was evaluated constantly, and participants underwent EEG biofeedback between recordings. Gertz and Lavie identified a 200-minute ultradian rhythmicity in both EEG and arousal measures and concluded that “[because] the observed ultradian and circadian EEG rhythmicities could be spuriously interpreted as learning curves under a biofeedback paradigm, it is argued that future designs should incorporate continuous baseline controls” (p. 694). For instance, if we compare EEG recorded at 1 p.m., during the circadian peak, to data collected a few hours before, our findings may be an effect of time of day as much as they are due to an intervention or group difference. We must minimize or control for homeostatic variation when making comparisons within and between individuals or conditions. Recording data at the same time of day is a reasonable means for minimizing time-of-day effects.

Altogether, the presented findings are consistent with a growing literature on homeostatic regulation of EEG and suggest that ultradian and circadian contributions of EEG spectral activity should be identified within clinical applications. Any study or evaluation of EEG activity that failed to consider and control for time of day would likely be subject to significant, systematic, and entirely unnecessary artifact.

## Acknowledgment

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