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Evaluation of the electroencephalogram in young cats

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Abstract

Objective—To characterize the electroencephalogram (EEG) in young cats.

Animals—23 clinically normal cats.

Procedures—Cats were sedated with medetomidine hydrochloride and butorphanol tartrate at 2, 4, 6, 8, 12, 16, 20, and 24 weeks of age and an EEG was recorded. Recordings were visually inspected for electrical continuity, interhemispheric synchrony, amplitude and frequency of background electrical activity, and frequency of transient activity. Computer-aided analysis was used to perform frequency spectral analysis and to calculate absolute and relative power of the background activity at each age.

Results—Electrical continuity was evident in cats 4 weeks old, and interhemispheric synchrony was evident in cats at all ages evaluated. Analysis of amplitude of background activity and absolute power revealed significant elevations in 6-week-old cats, compared with results for 2-, 20-, and 24-week-old cats. No association between age and relative power or frequency was identified. Transient activity, consisting of sleep spindles and K complexes, was evident at all ages, but spike and spike or wave discharges were observed in cats at 2 weeks of age.

Conclusions and Clinical Relevance—Medetomidine and butorphanol were administered in accordance with a sedation protocol that allowed investigators to repeatedly obtain EEG data from cats. Age was an important consideration when interpreting EEG data. These data on EEG development in clinically normal cats may be used for comparison in future studies conducted to examine EEGs in young cats with diseases that affect the cerebral cortex.

An EEG is a recording of ongoing electrical activity in the brain and is useful for noninvasive examination of cerebrocortical function. An EEG is used to evaluate patients with seizures, systemic metabolic diseases and intoxications, sleep disorders, and brain damage. It is also used to monitor depth of anesthesia. Two factors of paramount importance to the interpretation of EEG data are degree of vigilance and age.¹ The effect of the transition between wakefulness and sleep on EEGs is known.² Similarly, patient age (through associated changes in brain myelination, synaptogenesis, and degeneration) has profound effects on the EEG. Maturation changes include the development from discontinuous EEG activity to continuous EEG activity; development from asynchronous activity to synchronous interhemispheric activity; evidence of transient activity (sleep spindles, vertex waves, K complexes, and spike and sharp waves); and changes in frequency, amplitude, and sleep patterns.¹

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Maturation of the EEG in humans from preterm infants to adults has been extensively studied, with patterns of electrical activity recognized at specific ages.^{1,3,4} Similarly, studies of EEG maturation have been performed in a number of species, including rabbits,⁸ guinea pigs,³ dogs,^{7,8} horses,⁶ goats,⁵ and cattle.⁹ The timing and character of these maturational changes differ with the rates of brain development in these various species; thus, it is difficult to make comparisons among species.⁵ Although electrocorticogram maturation activity is evaluated in unsedated kittens,^{10,11} there is little data on use of the more clinically practical scalp recording technique.

Cats are affected by a number of developmental and neurodegenerative diseases that involve the prosencephalon; however, there is a lack of EEG data from young, clinically normal cats for comparison with data from diseased cats. The objective of the study reported here was to characterize the EEG in developing, clinically normal cats by use of a readily accessible sedation and recording protocol for use in collection of EEG data from cats between the ages of 2 and 24 weeks of age.

Materials and Methods

Animals

A total of 23 cats were evaluated during the course of this study. Cats were raised in the animal colony of the School of Veterinary Medicine at the University of Pennsylvania under National Institutes of Health and USDA guidelines. All procedures were approved by an institutional animal care and use committee.

Cats in the colony were bred to yield offspring with autosomal recessively inherited Niemann-Pick type C disease, although all cats evaluated were heterozygotic or had negative results when tested by use of a PCR-based DNA test at 1 day of age for the NPC1 missense mutation.¹² Heterozygotic cats did not have clinical deficits that were measurable during physical or neurologic examinations (including brain stem auditory-evoked response evaluations) or evident on the basis of clinicopathologic testing.¹³ Cats were housed at 21°C with food and water available ad libitum. Housing conditions included 12-hour light cycles (12 hours of light and 12 hours of darkness) and 1 to 15 air changes/h.

EEG acquisition

The EEGs were recorded from cats at 2, 4, 6, 8, 12, 16, 20, and 24 weeks of age. Recordings were obtained from 4 cats at 2 weeks of age, 4 cats at 4 weeks of age, 6 cats at 6 weeks of age, 4 cats at 8 weeks of age, 9 cats at 12 weeks of age, 9 cats at 16 weeks of age, 10 cats at 20 weeks of age, and 8 cats at 24 weeks of age.

For each EEG acquisition, cats were sedated with an IM injection of 30 µg of medetomidine hydrochloride^a/kg and 0.01 to 0.02 mg of butorphanol tartrate^b/kg IV to limit movement during electrode placement and EEG recording. While the cats were sedated, an ECG was continuously monitored. The EEG recordings were acquired in a darkened, quiet room.

Fifteen stainless-steel recording electrodes^c were placed in the subcutaneous tissues over the calvaria of each cat; this included 3 frontal (F3, Fz, F4), 3 central (C3, Cz, C4), 3 parietal (P3, Pz, P4), 2 aural (A1 and A2), 2 ocular (OS and OD), 1 intercanthus, and 1 reference electrode (**Figure 1**). The aural electrodes were placed at the caudal aspect of the zygoma at the tragus, and the ocular electrodes were placed immediately adjacent to the lateral canthi.

^aDomitor, Pfizer, New York, NY.

^bTorbugesic, Fort Dodge, Madison, NJ.

^cRochester Electro-Medical, Tampa, Fla.

The reference electrode was placed over the frontal sinus. In addition, 2 ECG leads (ECG1 and ECG2) and a ground electrode (which was located on the dorsal aspect of the neck) were placed; thus, there were a total of 18 electrodes. Because of the small size of the head in 2- and 4-week-old cats, the aural, ocular, intercanthus, and left and right central (C3 and C4) electrodes were omitted.

In a preliminary experiment, electrode placement was verified by use of a cadaver of a 26-week-old cat. Needles (25 gauge) were positioned at the same locations as the tips of the EEG recording electrodes. These needles were placed through the skin and into the underlying calvarium. The skin over the head was removed while the position of the needles was maintained. Then, 1-mm holes were drilled in the calvarium at the location of each needle tip.

The calvarium was removed by use of a Stryker saw, and the location of each drill hole was examined to determine the brain region beneath it. The F3 and F4 electrodes were at the precruciate gyri, with the Fz electrode in the longitudinal fissure. The C3 and C4 electrodes were in the rostral portion of the middle suprasylvian gyri, with the Cz electrode in the longitudinal fissure. The P3 and P4 electrodes were in the middle portion of the middle suprasylvian gyri, with the Pz electrode in the longitudinal fissure.

Commercially available software^d was used for data acquisition and storage. Electrode impedance was measured before each recording and was considered acceptable when < 10 k Ω . Display settings during recording were as follows: sensitivity = 5 μ V/mm, time = 30 mm/s, and bandpass filter = 0.5 to 70 Hz with a 60-Hz notch. Each EEG was recorded until patient movement associated with recovery from sedation was detected. At the end of each recording session, sedation was reversed by administration of atipamezole hydrochloride^e (5 μ g/kg, SQ).

EEG analysis

All EEG data were reviewed via a bipolar montage, except for interhemispheric synchrony for which a referential montage with reference to the sinus electrode was used. Recordings were visually inspected for electrical continuity, interhemispheric synchrony, amplitude and frequency of background electrical activity, and frequency of transient activity. Electrical continuity was identified when the amplitude of the recording was relatively steady, whereas discontinuity was identified when the recording alternated between bursts of activity and periods of amplitude attenuation.¹⁴ Interhemispheric synchrony and asynchrony were identified during any discontinuous portions of the EEG. Asynchrony was defined as bursts of morphologically similar EEG activity in homologous brain regions separated by > 1.5 seconds.¹⁴

Transient activity, including sleep spindles, vertex waves, K complexes, and spike and sharp waves, was measured over a 10-minute period that began 5 minutes after the start of the recording period. Computer-aided analysis by use of a software analysis package^d was also used to perform frequency spectral analysis and to calculate absolute and relative power of the background activity. The power spectral density (power spectrum) reflects the distribution of signal power over the various frequency bands. Variables that may be derived from the power spectrum include absolute power and relative power. Absolute power is the area under the curve of the power spectrum within the bandwidth under consideration. Relative power is the percentage of the power spectrum within a specific bandwidth as a function of the total power. Calculations were based on the C3-Cz derivation. Twenty 10-

^dNicolet One software, Nicolet Biomedical, Madison, Wis.

^eAntisedan, Pfizer, New York, NY.

second epochs of transient-free background activity were chosen from each recording; epochs were not selected from the 5 minute period at the beginning and ending of recordings because depth of sedation was not uniform. Recordings within each age group were compared for consistency. Results were compared among age groups to analyze age-related changes with respect to the EEG. Statistical analysis consisted of a Wilcoxon rank-sum test for absolute power calculations.

Results

The sedation protocol allowed for a continuous EEG recording with a range of 14 to 29 minutes (mean, 22 minutes) without movement artifacts. Bradycardia was a consistent and expected finding with the sedation protocol. All cats recovered without evidence of ill effects associated with the sedation protocol.

Visual examination of recordings

Evaluation via a bipolar montage revealed that background activity recorded from 2-week-old cats had periods of discontinuity in recordable electrical activity (**Figure 2**). In contrast, EEG recordings obtained from cats 4 weeks old had continuous electrical activity (**Figure 3**). Interhemispheric synchrony was present at 2 weeks of age and was maintained for all age groups.

Because synchrony was present in all derivations at all ages, measurements of background activity were performed by use of C3-Cz. Review of C3-Cz amplitude envelope measurements for each recording revealed that background activity for 2- and 4-week-old cats was low in amplitude (mean minimum voltage, 4.6 and 9.3 μ V, respectively; and mean maximum voltage, 14.7 and 19.2 μ V, respectively), with a range of 2.2 to 24.8 μ V and 5.9 to 22.3 μ V for 2- and 4-week-old cats, respectively). In comparison, 6- to 8-week-old cats had the highest amplitude for background activity among the cats in this study (mean minimum voltage, 17.6 and 17.0 μ V, respectively; and mean maximum voltage, 44.2 and 40.6 μ V, respectively), with a range of 7.7 to 66.6 μ V and 9.0 to 74.3 μ V for 6- and 8-week-old cats, respectively. After 8 weeks of age, amplitude decreased in all derivations until the recordings became steady with lower amplitude activity between 20 and 24 weeks of age (mean minimum voltage of 10.1 and 12.2 μ V, respectively; and mean maximum voltage of 28.3 and 28.8 μ V, respectively) with a range of 5.9 to 57.1 μ V and 7.4 to 48.2 μ V for 20- and 24-week-old cats, respectively.

Delta rhythms were prominent in all derivations, which indicate the tendency toward low-frequency activity in all age groups. Transient activity was detected in all recordings. In cats 4 weeks old and older, normal transient activity (primarily sleep spindles) were seen diffusely in all leads, had a duration of 1 to 2 seconds, and were characterized by a frequency of 8 to 13Hz. Normal transient activity was difficult to quantify in 2-week-old cats because of the discontinuity of the EEG in cats of this age. However, there was a subjective increase in the overall number of normal transient activities in cats > 12 weeks old, compared with results for cats < 8 weeks old. There was large variation in the amount of transient activity between 8 and 12 weeks of age, but little difference was detected in transient activity between 12 and 24 weeks of age.

Only a few paroxysms resembling sharp waves and spike or wave discharges were identified in 2-week-old cats (**Figure 4**). They were observed in all brain regions (frontal, central, and parietal) in all 4 cats of this age from which EEG recordings were obtained. In 2 cats, there was phase reversal predominantly at Pz, whereas the other 2 cats did not have an obvious recurring phase reversal. No atypical transient activities were identified in any cats > 2 weeks old.

Frequency spectral analysis

Calculations of absolute power (measurements made by use of C3-Cz) at each frequency bandwidth (delta, 0.5 to 4 Hz; theta, 4 to 8 Hz; alpha, 8 to 13 Hz; and beta, 13 to 30 Hz) revealed age-related changes (**Figure 5**). Absolute power for each bandwidth was at a minimum in 2-week-old cats, and maximum power at each bandwidth was evident at 6 and 8 weeks of age. Absolute power decreased progressively until reaching a plateau at 20 to 24 weeks of age. Significant increases in power were identified when delta, theta, alpha, and beta frequency bandwidths for 6-week-old cats were compared with results for 2-week-old cats and with results for 20- or 24-week-old cats.

No association was detected between age and relative power. Relative power calculations for each frequency bandwidth (ie, delta, theta, alpha, and beta) did not reveal patterns among the various groups from 2 to 24 weeks of age.

Discussion

Young cats have substantial postnatal maturation and development of the cerebral cortex.^{3,5,8} Maturation of cerebrocortical electrical activity has been described in awake kittens in which recordings were obtained by use of electrodes chronically implanted in the dura mater.^{8,15} These electrocorticograms allow for precise control of testing conditions and for recording of various states of consciousness in nonsedated animals. In contrast, EEG data collected from the scalp of sedated cats represents results for a simple, noninvasive technique; however, in contrast to the electrocorticogram studies,^{8,15} pharmacological effects of sedatives on electrical activity must be considered. For example, α_2 -receptor agonists promote slow-wave sleep in humans,¹⁶ horses,¹⁷ and rats.¹⁸ During physiologic or pharmacologically-induced slow-wave sleep, delta rhythms predominate and normal transients (sleep spindles and K complexes) appear.^{16,17} Similar results were obtained in dogs^{19,20} and cats.^{21,22} In dogs, the α_2 -receptor agonists xylazine and medetomidine were useful in minimizing movement artifact associated with EEG recording, and both resulted in a dose-dependent increase in delta activity.^{19,20} In cats, sedation achieved by administration of medetomidine and dexmedetomidine resulted in an increase in the power of the low-frequency bands (delta and theta), whereas sedation achieved by administration of medetomidine also resulted in the recording of spindles, K-complexes, and vertex sharp transients and the absence of paroxysmal activity and burst suppression.^{21,22} Our data are consistent with findings in other species that support similar effects for medetomidine in inducing slow-wave sleep in young cats.

In the study reported here, sedation and recording methods that can be used to reliably obtain EEG data from cats were described. By recording EEGs from cohorts of cats from 2 weeks until 6 months of age, differences were identified in continuity, transient activity, and background amplitude at various ages. Analysis of absolute power also revealed variation on the basis of cat age. At 2 weeks of age, which coincides approximately with when kittens open their eyes, there are periods of relative quiescence in electrical activity. The absolute power was lowest at this age. Transition to an EEG without cessation of background activity was between 2 and 4 weeks of age. By 4 weeks of age, there was electrical continuity, but amplitude and absolute power still remained low. There was a peak in activity between 6 and 8 weeks of age, which suggested a period of change in brain development during this time. The amplitude and absolute power subsequently decreased steadily to reach approximate values for adults by the time the cats reached 20 to 24 weeks of age.

Cats have small temporalis muscles, and the skull is relatively thin at the ages examined; however, changes in volume conduction cannot be ruled out as a possible confounder of the findings for amplitude and absolute power. Analysis of transient activity revealed normal

transient events indicative of sleep or sedation were present at all ages but that these were more prevalent in older cats than in younger cats. Rare paroxysmal events (spikes, waves, or sharp waves) from recordings obtained from 2-week-old cats had a phase reversal at Pz, which suggested a possible source for the discharges at the level of the middle suprasylvian gyri.

However, the phase reversal at Pz was only detected in 2 of the 4 cats at this age from which recordings were obtained. The paroxysmal events, although epileptiform and considered abnormal in older animals, may still be a normal finding in 2-week-old cats. Similar paroxysmal discharges have been detected in recordings of newborn humans and are considered to be age-normal events.¹

The EEG changes associated with age in kittens have been evaluated in awake cats with implanted cortical electrodes.^{10,11} In 1 of those studies,¹¹ investigators identified changes in sleep-state patterns that were evident when results for 10- and 20-day-old cats were compared with results for 40-day-old cats. Interestingly, these changes were similar and were detected at a similar age as the changes seen in the study reported here for cats at 6 weeks of age, compared with results for cats at 2 and 4 weeks of age. In the other study,¹⁰ investigators identified 5- to 8-second periods of extremely low voltage 1- to 3-Hz waves with occasional bursts of rhythmic 5- to 10-Hz activity in newborn cats. During the first 2 weeks after birth, there was a progressive increase in the amount and amplitude of electrocortical activity, with more frequent slow-wave activity and rhythmic activity (ie, spindling) at a frequency of 6 to 12 Hz. Occasional seconds-long bursts of small-amplitude 10- to 15-Hz activity were also recorded. By the time cats were 4 weeks old, the recordings had slow waves remaining in the background recordings with superimposed 15- to 20-Hz, 20- to 30- μ V activity. In comparison, adult cats had no low-voltage slow-wave activity or activity > 30 Hz.¹⁰ Although not directly comparable because of the recording techniques used and the lack of sedation, investigators in that study¹⁰ also identified periods of discontinuity in EEGs obtained from cats > 2 weeks old. Unfortunately, there was no data in the study¹⁰ that could be used for comparison of recordings for cats between 4 weeks of age and adult.

It is unknown precisely which anatomic developments in the brain account for these changes in amplitude, absolute power, and transient activity, but simple gross examination of feline brains obtained from cats between 1 and 8 weeks of age reveals marked distinctions. Although the same sulcal pattern is present in 1-week-old cats, it becomes much more pronounced and gyri deepen by 8 weeks of age, in addition to the obvious increase in the size of the brain. It has been suggested that myelination is perhaps the most important postnatal maturational change in the CNS.¹ This process, which increases substantially in cat brains up to at least 16 weeks of age, could correlate with the electrical changes seen on EEG recordings.²³ In humans, maturation of the brain's electrical activity extends well into young adults, but the timing and occurrence of a similar delay in the development of the brains in cats has not been determined. Analysis of our data suggests that this is indeed the case and that age is an important consideration when interpreting EEG data in a young cat.

Shortcomings of the experimental design included the inability of the investigators to serially record from a large cohort of cats at each time point. Indeed, no individual cat was examined at > 4 time points. Six cats were evaluated serially from 6 until 16 weeks of age, and data from these cats were not different from data collected from all cats at these ages. However, recordings obtained from 2- and 4-week-old cats could not be collected from those same cats at later ages. Although these cats were genotypically and clinically normal, it is possible that data in these cats was not representative of data from all cats at the same ages. The inability to obtain a recording from each cat serially over a 24-week period was

attributable to the fact the study was performed over a limited time period with clinically normal cats that were involved in other ongoing studies but that were made available to the investigators for use in the study reported here. Although all cats examined were clinically normal at the time of evaluation, a more rigorous approach would have been a longitudinal evaluation of a large cohort of cats.

These data on EEG development in clinically normal cats may be used for comparison in future studies conducted to examine EEG maturation in cats with developmental or genetic diseases that affect the cerebral cortex. Given that the use of animals is crucial in scientific studies, we believe that the EEG data from these clinically normal cats may be applicable for feline cerebrocortical development in general.

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Abbreviation

EEG Electroencephalogram

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Figure 1.

Diagram for the placement of stainless-steel electrodes for EEG recordings in young cats. Sixteen electrodes were placed subcutaneously over the head and neck region. These consisted of frontal (F3, Fz, and F4), central (C3, Cz, and C4), parietal (P3, Pz, and P4), aural (A1 and A2), ocular (OS and OD), intercanthus (IC), ground (N), and reference (R) electrodes. The ground electrode was placed in the dorsal aspect of the neck, and the reference electrode was placed over the frontal sinus.

Figure 2.

An EEG recording from a representative 2-week-old cat. Notice the period of electrical discontinuity (example between arrows; sensitivity=5 $\mu\text{V}/\text{mm}$ and time=30 mm/s)

Figure 3.

An EEG recording from a representative 6-week-old cat (A) and a representative 24-week-old cat (B). Notice the higher amplitude waveforms evident at 6 weeks of age (sensitivity=15 μ V/mm and time=30 mm/s)

Figure 4.
The EEG recordings from 2-week-old cats. Notice the rare spike or wave paroxysms indicated by * (sensitivity=5 μ V/mm and time=30 mm/s)

Figure 5.

Mean $\pm$ SD absolute power calculations for delta (A), theta (B), alpha (C), and beta (D) frequency bandwidths for EEG recordings obtained for cats from 2 to 24 weeks of age. Notice that the scale on the y-axis differs among panels. *Value reflects a significant ($P < 0.05$) change in power compared with results for 6-week-old cats.