Cocaine-Induced Increases in EEG Alpha and Beta Activity: Evidence for Reduced Cortical Processing

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To understand the effects of cocaine on the cerebral cortex, 14 male polydrug abusers were enrolled in a study on the effects of cocaine on the electroencephalogram (EEG). The experimental treatments were placebo, 20 mg cocaine or 40 mg cocaine IV administered in a double-blind, pseudorandom design. The EEG was recorded from 13 electrode positions over the left hemisphere during a 3-minute baseline recording and for 30 minutes after initiation of the IV injection. The spectral power for delta, theta, alpha and beta EEG bands was calculated from data collected in each 3-minute interval. Cocaine significantly increased beta in frontal and central areas and enhanced alpha in frontal and temporal regions. Cocaine-induced increases in EEG beta power had a cortical distribution similar to those produced by barbiturates and benzodiazepines. As all of these drugs reduce cortical glucose metabolism, the increases in beta power may reflect a reduction in cortical neural activity. ***[Neuropsychopharmacology 11:1–9, 1994]***

KEY WORDS: *Cocaine; EEG; Drug abuse*

Despite the epidemic of cocaine abuse during the past two decades, little is known about the neurophysiological effects of this drug in humans. Berger, the first to study effects of cocaine on the human EEG, noted that 30 mg of subcutaneous cocaine increased EEG alpha abundance in two subjects (Berger 1931). Using an amplifier that allowed the recording of EEG in the beta frequency range, he later observed an increase in EEG beta in one subject who received 20 mg cocaine subcutaneously (Berger 1937). Herning et al. (1985) replicated the observation that cocaine increased EEG beta in a large sample of subjects who received intravenous (IV) and oral cocaine. Both Berger and Herning interpreted the increase in EEG beta as an indication of increased cortical arousal.

Increases in EEG beta do not always indicate increased cortical arousal or activity. Whereas barbiturates and benzodiazepines increase EEG beta activity in frontal and central areas (Benowitz et al. 1980; Domino et al. 1989; Manmaru et al. 1989), both classes of drugs also reduce cerebral glucose utilization (Theodore et al. 1986; Buchsbaum et al. 1987; Foster et al. 1987; de Wit et al. 1991), an index of brain function (Sokoloff 1972). Amphetamine and cocaine also reduce cortical glucose metabolism and blood flow in human subjects (Wolkin et al. 1987; Kahn et al. 1989; London et al. 1990). The view that increases in EEG beta, produced by stimulant drugs in human subjects, may reflect decreased cortical activation agrees with observations that dopamine, norepinephrine, and indirect dopaminergic agonists de-

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crease neuronal firing in mesolimbic areas of the rodent brain (Bunney and Aghajanian 1978; Siggins 1978).

The present report investigates the anterior-posterior distribution of cocaine-induced changes in the human EEG. Since the EEG beta changes produced by the drugs noted above were either maximal in frontal areas or were observed first in frontal areas and were not asymmetric (Benowitz et al. 1980; Domino et al. 1989; Manmaru et al. 1989), we concentrated our limited EEG recording capacity on the left hemisphere. One objective of this work was to assess the potential relationship between self-reports of alterations in mood and EEG effects of cocaine in different cortical areas. Previous studies used only a limited number of recording sites and short EEG recording periods. We now report the EEG changes from 13 sites before and continuously for 30 minutes after the injection of placebo, and 20- and 40-mg IV *l*-cocaine hydrochloride.

Table 1. Demographic Characteristics of the Subjects

Age[1] (years)	32.6 ± 5.4
Education[1] (years)	11.6 ± 1.8
Race[2]	Black 8 White 6
Marital Status[2]	Never Married 6 Married 1 Separated/Divorced 7
Occupation[2]	
Construction Worker 7	Skilled Trade 2
Truck Driver 1	Factory Worker 1
Courier 1	Porter 1
Video Tape Editor 1	
Shipley Institute for Living Scale[1]	
Full Scale IQ	100.6 ± 11.5
Conceptual Quotient	96.2 ± 14.3
Abstraction Quotient	107.4 ± 12.8
Vocabulary T-Score	50.6 ± 11.8
Abstraction T-Score	54.4 ± 6.1

[1] Values shown are mean and standard deviations.
[2] Values shown are numbers of subjects in each category.

MATERIALS AND METHODS

Subjects

Eighteen men were recruited for this study, with cocaine abuse as an inclusionary criterion. One subject was excluded because of a subarachnoid cyst noted on magnetic resonance imaging (MRI), and the EEG data from three subjects were incomplete either because of technical difficulties of unusual sensitivity to a test dose of 20 mg cocaine. Characteristics of the 14 subjects who completed the study are listed in Table 1. Self-reports of drug abuse were obtained by an interview using a two-page questionnaire developed at the Addiction Research Center and administered in conjunction with the Addiction Severity Index (McLellan et al. 1985) (Table 2). Aside from substance abuse, all subjects were healthy as determined by a physical examination, including electrocardiogram and standard diagnostic laboratory tests. They were screened for psychiatric disorders by the National Institute on Mental Health Diagnostic Interview Schedule, which was adapted for computerized administration (Robins et al. 1981). Diagnostic criteria were defined according to the DSM-III. The only current Axis I diagnoses for which subjects met criteria were substance abuse disorders. The only Axis II diagnoses that were allowed were borderline and/or antisocial personality disorders. Three subjects were diagnosed as having antisocial personality disorder and none met criteria for borderline personality disorder. All subjects were seronegative for human immunodeficiency virus (HIV-I), as determined by ELIZA and Western blots. They were all right-handed, as measured by a questionnaire (Annett 1970). All subjects gave written informed consent according to procedures outlined by the institutional review boards of Johns Hopkins Medical Institutions and Francis Scott Key Medical Center, a Hopkins-affiliated hospital where the Addiction Research Center is located.

Among the many difficulties with studies that involve administration of cocaine to human subjects is the variability in drug use by nonresidential research subjects. Therefore, subjects in the current study resided on a limited-access research ward, with screening of urine to detect and exclude self-administration of abused drugs. Except for nicotine and caffeine, which were available in cigarettes and beverages, respectively, the subjects were drug-free for 6 to 16 days (mean 9.4 ± 3.1 days) before testing began in the study. After EEG testing, with 0, 20, and 40 mg IV cocaine, subjects participated in measurement of regional cerebral metabolic rates for glucose by the [^{18}F]fluorodeoxyglucose positron emission tomographic (PET) method. The effect of 40 mg cocaine versus placebo, as determined by PET scanning, in eight of the subjects who participated in the present study has been reported (London et al. 1990).

Experimental Design

Each subject was tested four times. The test sessions were separated by at least 24 hours. The first session was used to familiarize the subject with the testing environment. The first treatment always was a placebo IV injection that was given in a single-blind manner. Only heart rate, blood pressure, and subjective effects were monitored. EEG was recorded during the next three sessions. Placebo, 20 mg, and 40 mg cocaine were administered in a double-blind, pseudorandom sequence. The 20 mg dose was always given before the 40 mg dose, but placebo occurred randomly in the sequence. This sequence was used to protect the subjects from possible adverse effects of the higher dose of cocaine.

Table 2. Self-Reported Drug Use History

Drug	Number of Subjects with Lifetime[1]/ Current[2] Use	Age of First Use (years)[3]	Number of Days in Last 2 Weeks[3]	Recent Use Amount/14 Days[3]
Cocaine	14/13	21.3 ± 5.5 (13 to 35)	5.1 ± 3.0 (1 to 10)	0.6 ± 0.5 g (0.1 to 2.0)
Amphetamine	4/2	21.6 ± 0.9 (16 to 25)	4.5 ± 3.1 (1 to 8)	0.5 ± 0.3 g (0.2 to 0.8)
Heroin	12/7	18.8 ± 3.6 (15 to 25)	4.7 ± 3.1 (1 to 10)	0.1 ± 0.1 g (0.05 to 0.1)
Barbiturates	4/1	16.8 ± 2.1 (15 to 20)	1.0	200 mg/day
Hallucinogens	7/0	16.3 ± 1.1 (15 to 18)		
Marijuana	14/9	15.4 ± 3.5 (12 to 25)	5.4 ± 3.5 (2 to 12)	1.1 ± 13.2 joints (2 to 40)
Alcohol	14/13	14.3 ± 1.8 (12 to 17)	5.7 ± 4.8 (1 to 14)	8.0 ± 5.0 drinks (2 to 18)
Nicotine	13/13	14.1 ± 40.2 (8 to 23)	13.7 ± 1.1 (10 to 14)	20.0 ± 7.9 cigarettes/day (10 to 30)

[1] Number of subjects who used the drug.
[2] Number of subjects who are currently using the drug.
[3] Mean ± standard deviation (range).

Drug Treatments and Test Sessions

The placebo dose was 2.0 ml of 0.9% NaCl (saline). The doses of cocaine were prepared by dissolving 20 or 40 mg of *l*-cocaine HCl in saline to an injection volume of 2.0 ml. They doses were infused intravenously over a period of 10 seconds, vital signs (electrocardiogram, blood pressure) and subjective ratings were monitored, and spontaneous EEG recorded in a sound-attenuated, electrically shielded chamber. Heart rate, systolic and diastolic blood pressure were recorded at 60 and 30 minutes before the injection and at 1, 3, 5, 10, 15, 20, and 30 minutes after the injection. A verbal response from "0" to "4," indicating the strength of the drug effect, was elicited by a "beep" prompt at 60-second intervals. The subject had a blindfold over his eyes and listened to white noise during the EEG recording procedure. A seven-item visual analog scale (VAS) also was used to monitor the subjective effects of cocaine (London et al. 1990). The VAS was administered at 30 and 60 minutes before the injection and at 30 minutes after the injection.

EEG Recording and Analysis Procedures

The EEG was recorded from the following International 10/20 scalp sites: F_{pz}, F_z, C_z, P_z, O_z, F_{p1}, F_3, C_3, P_3, O_1, O_z, F_7, T_3, and T_5. The reference site was the tip of the left ear (A_1). The electrooculogram (EOG) was recorded from above to the temporal side of the eye. Silver/silver chloride electrodes were used at all locations. The EEG and EOG were amplified using Grass (Model 7P511) amplifiers with 1-Hz to 100 Hz half amplitude band pass and a 60-Hz notch filter. The amplifiers were calibrated with a 5-Hz, 50-μvolt square wave (Grass Calibrator, Model SWC1B). The calibration signal and EEG signals were input into amplifiers via the electrode board in the recording chamber. Their output was recorded on an IBM/AT personal computer with a Data Translation (Model DT2821-F-SE) analog to digital convertor. Each EEG or EOG channel was sampled at 5.0 msec intervals using software developed in-house for this purpose. The interchannel sampling time was 40.0 μsec. A 3-minute predrug recording (pre-) and a 30-minute postdrug recording were obtained. The postdrug recording was synchronized with the starting of the 10-second IV injection period. The raw EEG and EOG data were saved for subsequent analysis.

A fast Fourier transform with a Tukey-Hamming window (Chamberlin 1985) was calculated on each 512 point sample (2.56 seconds) of artifact-free EEG data. EOG and movement artifact were rejected by a computer algorithm, as in Herning et al. (1985). The power spectra were resolved into 0.4-Hz increments from 0.0 to 32.8 Hz. The resultant power spectra were averaged for each 3-minute period (pre- and 10 postdrug average spectra). The power spectra were divided into the delta (0.4 to 4.0 Hz), theta (4.4 to 8.0 Hz), alpha (8.4 to 13.2 Hz), and beta (13.6 to 32.8 Hz) bands. Total spectral power (μV^2) was measured in the respective bands. Left hemisphere topographic maps of banded EEG spectral power were constructed using the linear four point nearest-neighbor technique (Perrin et al. 1987). The changes from baseline in EEG spectral power in delta, theta, alpha, and beta bands were analyzed by two factor repeated measures [Dose (placebo, 20 mg,

40 mg) by Time (the 10 3-minute periods)], analysis of variance (ANOVA) for each electrode using conservative Greenhouse-Geisser, adjustment as recommended for such data (Jennings and Wood 1976; Vasey and Thayer 1987). The cardiovascular measures were analyzed by a two factor repeated measures [Dose (placebo, 20 mg, 40 mg) by Time (two baseline and seven values obtained after the injection of the test compound)] ANOVA.

RESULTS

Both doses of cocaine significantly increased heart rate (Dose: $F = 30.97$, $df(2,24)$, $p < .0001$; Dose × Time; $F = 13.48$, $df(16,192)$, $p < .0001$), diastolic (Dose: $F = 21.58$, $df(2,24)$, $p < .0001$; Dose × Time: $F = 4.16$, $df(16, 192)$, $p < .01$), and systolic (Dose: $F = 33.15$, $df(2,24)$, $p < .0001$; Dose × Time: $F = 8.28$, $df(16,196)$, $p < .0001$) blood pressure (Figure 1). The difference between the effects of 20 and 40 mg cocaine on cardiovascular measures was small. The postdrug means for "beep" prompt and the VAS responses are listed in Table 3. Both doses of cocaine significantly elevated the responses to the "beep" prompt and scores on the VAS, but no significant differences were observed between the doses.

Cocaine significantly increased EEG beta power (Table 4). The changes from baseline scores at F_{pz}, F_z, F_3, F_7, C_z, and C_3 electrodes revealed significant main effects of Dose. Topographical maps for mean EEG beta power are displayed in Figure 2 (bottom). Significant increases in EEG spectral beta power were observed clearly in frontal and central cortical areas. Although both doses of cocaine increased in EEG beta, the effect appeared to wax and wane over time. The increase in beta due to the 40 mg dose of cocaine continued over the 30-minute period. Little or no increase was found after the injection of placebo.

The results for EEG alpha power are shown in Table 5. The main effect of Dose was significant for the change from baseline score at F_{pz}, F_z, F_{p1}, F_7, and T_5 electrodes. The significant increase in EEG alpha spectral power occurred in both frontal (F_{pz}, F_z, F_{p1}, and F_7) and temporal (T_5) regions. Mean topographical maps for EEG alpha spectral power are presented in Figure 2 (top). The main effects of Dose and Dose by Time interactions for EEG delta and theta spectra power were not statistically significant.

To explore possible relationships between the EEG alpha and beta and other measures of responses to cocaine, a limited set of correlations was calculated. The correlation of all EEG, self-report, and cardiovascular measures would have resulted in more variables than cases. Therefore, correlations were limited to a subset

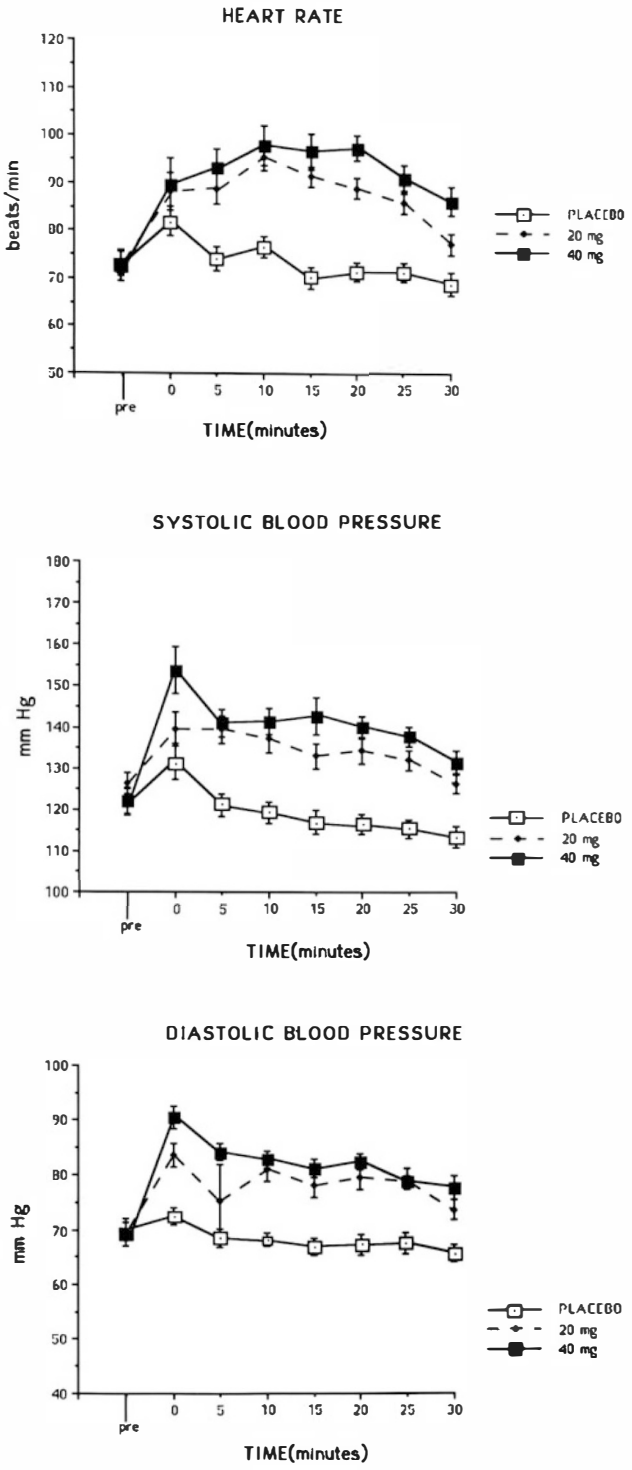

Figure 1. The mean of the cardiovascular measures assessed 30 minutes before and at 1, 3, 5, 10, 15, 20, and 30 minutes after injection of placebo, 20 mg, and 40 mg cocaine ($n = 14$). The top group of the graph shows heart rate, the middle shows systolic blood pressure and the bottom shows diastolic blood pressure. Bars indicate standard errors.

Table 3. Subjective Response to "Beep" Prompt and VAS

Subjective Measure	Placebo	Cocaine 20 mg	Cocaine 40 mg
"Beep"[1]			
Feel drug	1.8 ± 1.8*	19.6 ± 4.4	21.3 ± 6.8
VAS[2]			
Strong effects	5.1 ± 5.3*	38.2 ± 9.1	49.6 ± 10.1
Good effects	4.9 ± 5.2*	50.0 ± 10.7	55.0 ± 11.3
Bad effects	2.6 ± 2.4	6.3 ± 3.3	8.8 ± 5.1
Like drug	7.6 ± 7.5*	48.4 ± 10.2	51.9 ± 12.3
Feel high	6.8 ± 6.4*	43.6 ± 9.9	47.2 ± 11.2
Take again	10.4 ± 10.0*	63.4 ± 12.2	56.0 ± 12.3
Energetic	5.8 ± 6.0*	47.9 ± 10.8	48.0 ± 10.0

[1] The subject was instructed to score his response to the question "How much do you feel the drug?" at the sound of the "beep" prompt.
[2] The Visual Analog Scales were presented as seven items, each associated with a 100-mm line, on which the subject scored his response.
* Significant Drug Effect in ANOVA. Placebo was significantly different than both cocaine doses using Bonferroni post hoc test, $p < .05$.

of the variables. Correlations of "beep" prompt response, VAS scores, and cardiovascular measures with EEG beta at F_{pz} and with EEG alpha at F_{pz} and T_5 were calculated at each dose (Table 6). The F_{pz} and T_5 electrode sites were selected because they showed clear effects of cocaine. At both electrodes, EEG alpha activity was positively correlated with heart rate after the 40-mg dose of cocaine. EEG alpha was also negatively correlated with the VAS item, "use again." Heart rate and systolic blood pressure were significantly correlated with beta power for 40-mg cocaine at F_{pz}. Another set of correlations was calculated with the placebo values subtracted from each values for the two cocaine sessions on the cardiovascular, self-report, and EEG measures selected in the previous analysis. This procedure attempts to adjust for any bias in data from the placebo session. No significant correlations were observed for either dose and either EEG band.

Table 4. Total EEG Beta Power (μV^2): Mean Change Scores

Site	Placebo	Cocaine 20 mg	Cocaine 40 mg	Pooled[2] Standard Deviation	Dose Main Effect F(2,13)	Dose Main Effect p	Greenhouse-Geisser Probability
F_{pz}	3.4	24.8	245.5	218.2	8.721	0.0013	0.0064*
		|.....|[1]					
			|.....|[1]				
F_z	−164.2	19.8	243.7	105.5	11.053	0.0003	0.0005*
		|.....|[1]					
F_{p1}	−6.6	390.3	2105.0	611.2	3.771	0.0365	0.0734
F_3	−54.2	254.0	534.3	203.4	5.230	0.0123	0.0334*
		|.....|[1]					
F_7	−21.2	161.5	419.5	138.4	7.786	0.0022	0.0088*
		|.....|[1]					
C_z	−68.6	40.4	174.6	92.2	5.070	0.0138	0.0203*
		|.....|[1]					
C_3	9.1	106.7	349.4	117.1	5.604	0.0095	0.0194*
		|.....|[1]					
T_3	122.7	455.1	366.7	195.7	1.815	0.1829	0.1956
P_z	−120.5	4.2	198.2	145.7	2.817	0.0781	0.0942
P_3	−59.8	56.0	169.2	120.7	3.028	0.0657	0.0706
T_5	18.5	415.1	460.1	340.0	2.541	0.0982	0.1306
O_z	−27.5	48.6	201.8	99.6	2.241	0.1265	0.1434
O_1	−33.2	70.4	172.5	106.8	2.562	0.1092	0.1092

[1] Significant difference between means by Bonferroni post hoc test, $p < (0.05/3) = 0.0167$. Vertical bars indicate which means differ.
[2] Mean of the three standard deviations.

Table 5. Total EEG Alpha Power (μV^2): Mean Change Scores

Site	Placebo	Cocaine 20 mg	Cocaine 40 mg	Pooled[2] Standard Deviation	Dose Main Effect $F(2,13)$	Dose Main Effect p	Greenhouse-Geisser Probability
F_{pz}	68.4	145.8	485.4	116.7	6.544	0.0050	0.0171*
		|.....|[1]					
		|.....|[1]					
F_z	19.8	67.1	198.8	56.1	5.825	0.0081	0.0170*
		|.....|[1]					
F_{p1}	90.1	264.6	982.8	256.7	4.347	0.0235	0.0511
F_3	25.0	266.6	418.4	165.7	2.460	0.1051	0.1251
F_7	22.6	75.1	217.9	61.6	6.523	0.0051	0.0118*
		|.....|[1]					
C_z	5.9	109.0	112.9	59.0	3.429	0.0477	0.0505
C_3	26.5	61.1	158.0	55.0	3.250	0.0550	0.0727
T_3	37.3	122.4	109.5	49.9	2.959	0.0695	0.0611
P_z	5.8	139.8	187.4	89.0	2.059	0.1470	0.1645
P_3	18.7	95.5	158.5	57.8	2.881	0.0741	0.0752
T_5	35.6	120.6	175.6	58.6	4.743	0.0175	0.0197*
		|.....|[1]					
O_z	52.6	127.0	190.7	69.8	3.070	0.0635	0.0670
O_1	65.3	227.1	212.2	70.6	2.028	0.1518	0.1632

[1] Significant difference between means by Bonferroni post hoc test, $p < (0.05/3) = 0.0167$. Vertical bars indicate which means differ.
[2] Mean of the three standard deviations.

DISCUSSION

Cocaine increased EEG beta in frontal and central cortical areas and increased EEG alpha in frontal and temporal cortical areas. The increase in beta persisted for 30 minutes after the 40 mg dose of cocaine, but it waxed and waned. The oscillations in the EEG response to both doses of cocaine may represent phasic changes in factors that influence fast EEG activity. The observation that increases in EEG beta were larger than those observed for EEG alpha reinforce and extend the previous reports of cocaine-induced increases in EEG beta (Berger 1937; Herning et al. 1985) and alpha (Berger 1931; Lukas 1993). Likewise, we replicated the effects of cocaine on cardiovascular parameters and self-reported measures of mood (Fischman et al. 1976, 1983; Javaid et al. 1978).

Table 6. Correlations of EEG Measures with Self-Report and Cardiovascular Measures

	Alpha Power at F_{pz}			Alpha Power at T_5			Beta Power at F_{pz}		
		Cocaine			Cocaine			Cocaine	
	Placebo	20 mg	40 mg	Placebo	20 mg	40 mg	Placebo	20 mg	40 mg
Heart rate	−0.463	0.129	0.898*	−0.537	−0.096	0.788*	−0.639*	−0.379	0.573*
Blood pressure									
Systolic	0.294	0.188	−0.037	−0.514	−0.191	−0.021	−0.750*	−0.326	−0.125
Diastolic	−0.398	−0.061	−0.225	−0.635	0.186	−0.398	−0.424	0.040	−0.491
Beep: Feel	0.322	−0.685	0.102	−0.071	−0.546	0.039	−0.076	−0.095	−0.285
VAS (n = 10)									
Strong	0.322	−0.475	−0.107	−0.071	−0.318	−0.273	−0.076	0.026	−0.458
Good	0.322	−0.731#	−0.150	0.079	−0.530	−0.428	−0.076	−0.092	−0.565
Bad	0.252	−0.029	−0.257	−0.071	0.448	0.151	0.373	0.428	−0.290
Like	0.322	−0.548	−0.192	−0.071	−0.394	−0.434	−0.076	−0.013	−0.611
High	0.322	−0.583	−0.087	−0.071	−0.442	−0.245	−0.076	−0.012	−0.479
Use again	0.322	−0.711#	−0.136	−0.071	−0.453	−0.340	−0.076	−0.169	0.607
Energetic	0.322	−0.466	−0.051	−0.071	−0.173	−0.278	−0.076	−0.372	−0.464

* $p < .05$, $df = 12$.
\# $p < .05$, $df = 8$.

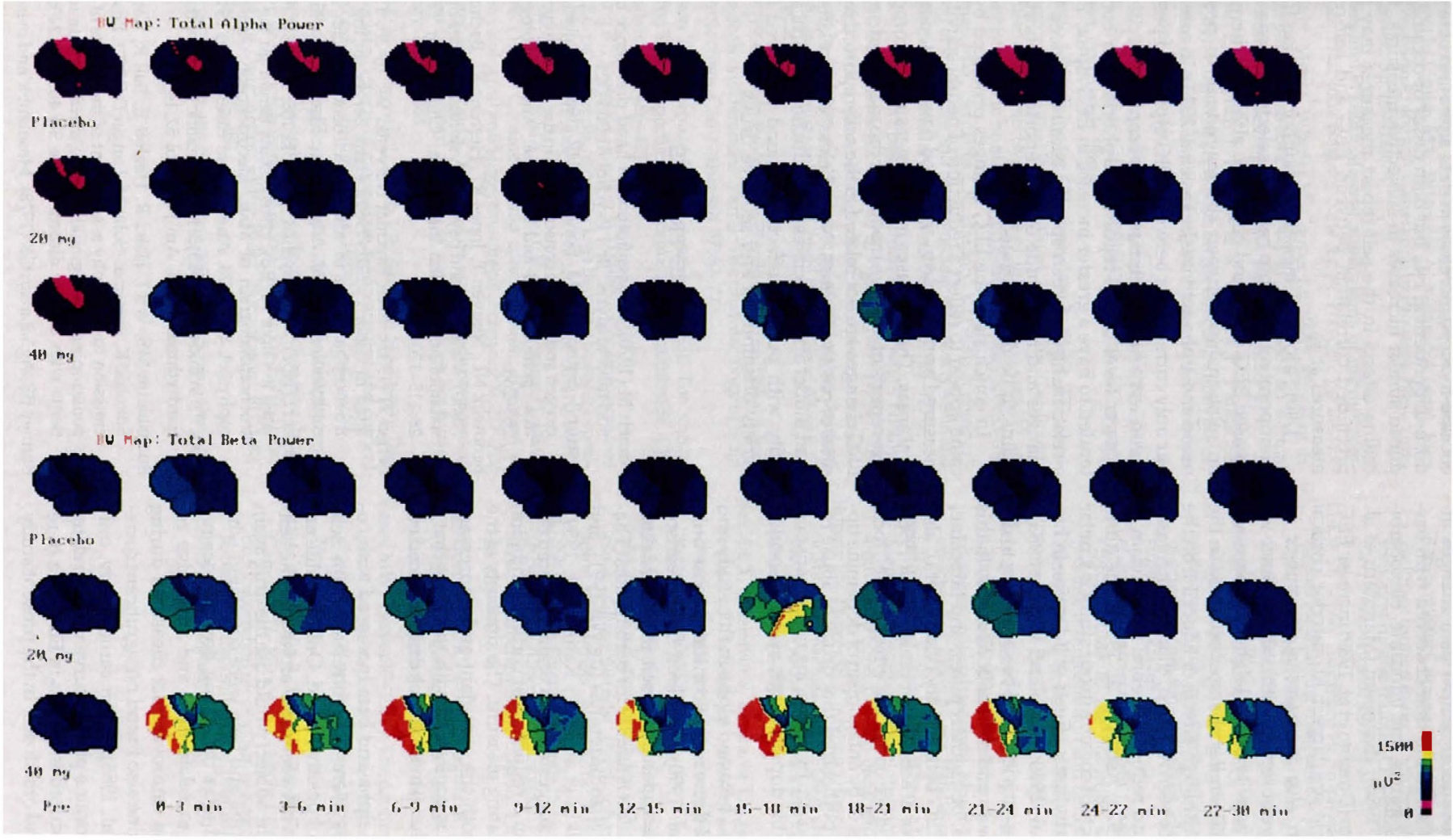

Figure 2. (*Top*) Topographical maps of total EEG alpha power (8.4 to 13.2 Hz) averaged over each 3-minute period at each treatment (n = 14). The top row of the maps show power after the injection of placebo, and the bottom rows show the effects of 20 mg and 40 mg cocaine, respectively. Each map shows the left hemisphere with the frontal cortex on the left. (*Bottom*) Topographical maps of total EEG beta power (13.6 to 32.8 Hz) averaged over each 3-minute epoch at each dose (n = 14). The top row of the maps show power after the injection of placebo, and the bottom rows show the effects of 20 mg and 40 mg cocaine, respectively. Each map shows the left hemisphere with the frontal cortex on the left.

The cortical distribution of EEG beta changes induced by cocaine is similar to that observed with barbiturates, benzodiazepines, and lidocaine. Hexobarbital (Benowitz et al. 1980), diazepam (Manmaru et al. 1989), and midalolam (Domino et al. 1989) increase EEG beta, and the effects are largest in anterior cortical regions. Midalolam also increases alpha power in posterior areas, as we observed with cocaine. Since we only recorded EEG activity on the left hemisphere, we can only suggest that similar changes occurred in the right hemisphere. Although effects of lidocaine on the human EEG have not been reported, this drug increases beta EEG activity and reduces cerebral metabolism in rats (Sabake et al. 1974; Astrup et al. 1981). The duration of the CNS effects of cocaine in our study is similar to that of the antiarrhythmic effects of lidocaine in humans (Harrison et al. 1963; Block and Winkle 1983).

Increases in beta activity could be secondary to decreased cortical activity and metabolic demand. In this regard, barbiturates, benzodiazepines, and lidocaine, which all increase EEG beta activity (vide supra), also reduce cortical neuronal activity (for review, Hall 1990). Cocaine might produce such an effect by its local anesthetic properties or by antagonism of dopamine uptake. It has been hypothesized that drugs of abuse reduce cerebral metabolism by enhancing neurotransmission in the mesolimbic dopaminergic system (London and Morgan 1993).

Increases in EEG beta and alpha in this study and previously reported decreases in cortical glucose utilization (London et al. 1990) and blood flow (Pearlson et al. 1993) were accompanied by self-reports of positive affect. The situation is similar for barbiturates (Theodore et al. 1986), benzodiazepines (de Wit 1991), and amphetamine (Wolkin et al. 1987; Kahn et al. 1989). London et al. (1990) suggested that cocaine-induced euphoria resulted from a reduction of cortical inhibition of limbic areas mediating pleasure. The similarity of the EEG response to both the stimulant and depressant drugs noted above is consistent with the view that a common brain mechanism underlies drug-induced euphoria in humans.

Although EEG alpha and beta increased with cocaine, the increases were not correlated with self-reported measures of positive mood. Only a significant negative correlation between EEG alpha and the self-reports of whether the subject would use the drug again was found. EEG alpha and beta were correlated with heart rate observed after the 40 mg dose of cocaine. Previous attempts to relate EEG and subjective responses or EEG and cardiovascular measures during intoxication by cocaine also found no significant correlations (Herning et al. 1985). In our earlier study, only the area under the cocaine plasma curve was correlated with the cocaine-induced increases in EEG beta in response to both IV and oral doses. In the present study, cocaine-induced increases in EEG alpha and beta were dose-dependent at F_{pz}, but both doses of cocaine produced similar increases in subjective measures. Such ceiling effects in the self-report measures may have precluded correlation between EEG and self-report measures at F_{pz}.

Using a joystick measure of euphoria, Lukas found a temporal relationship between selected epochs of increased EEG alpha and euphoria, although there was no relationship between the magnitude of positive mood and alpha activity (Lukas et al. 1993). In contrast, our only correlations between EEG alpha and positive mood were negative but not significant. Subjects with a lower level of self-reported euphoria after cocaine tended to have a greater increase in EEG alpha. Thus, a relationship between specific cocaine-induced EEG changes and magnitude of self-reported euphoria remains to be demonstrated.

In conclusion, the EEG changes produced by cocaine appear to reflect a reduction of neural activity, as measured by metabolism and blood flow in anterior cortical areas. The increases in EEG measures accompany self-reports of positive mood, but the magnitude of the EEG changes are not related to the self-reported intensities of positive feelings. Nonetheless, our working human model also associates the reduction of cortical activity with positive effects on mood produced by a variety of stimulant and sedative drugs.

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