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Cocaine's effects on detection, discrimination, and identification of auditory stimuli by baboons

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Abstract

The perceptual effects of cocaine were examined under conditions that required baboons to detect the presence of tones as well as to identify tones of different pitches, and the results compared to the results of prior studies on cocaine's effects on the detection of tones, the discrimination of different tone pitches, and the discrimination of different human vowel sounds of similar pitch. A reaction time procedure was employed in which baboons were trained to press a lever in the presence of a visual "ready" signal, and release the lever only when one tone pitch occurred, but not release the lever when a second, different tone pitch occurred. Changes in the percentage of correct detections and median reaction times for each tone were measured following intramuscular administration of cocaine (0.01–1.0 mg/kg). Cocaine impaired tone identification and shortened reaction times to the tones in all baboons. Cocaine's effects on accuracy, however, were primarily due to elevations in false alarm rates, as opposed to detection of the stimuli themselves. The results demonstrate that cocaine impairs the discriminability of tone pitches in baboons, and that such impairments can depend upon the type of stimuli employed (tones vs. speech sounds) and the type of procedure employed (discrimination vs. identification).

Keywords: Cocaine; Auditory perception; Discrimination; Detection; Identification; Baboon; Reaction time; Lever release

1. Introduction

The wide-ranging effects of cocaine on behavior reported in the literature suggest that cocaine interacts with numerous biological and behavioral processes. In rats, for example, cocaine has been reported to enhance accuracy in a vigilance task (Grilly and Grogan, 1990; Grilly and Nocjar, 1990), decrease response latencies (Grilly, 1992), and lower the threshold for the reinforcing effects of brain stimulation (Kornetsky and Esposito, 1981). On the other hand, cocaine has been reported to impair discriminative motor control in rats (Falk and Lau, 1991), elevate the threshold for the detection of brain stimulation in rats (Kornetsky and Esposito, 1981), and decrease the accuracy and rate of completing complex response sequences in monkeys (Branch and Sizemore, 1988). In humans as well, cocaine has been shown to increase Vigor and Arousal scores on the Profile of Mood States (POMS) inventory (Foltin and Fischman, 1991), improve performance accuracy on a digit symbol substitution test (Higgins et al., 1990), and improve reaction time speed on a visual attention task (Stillman et al., 1993). In contrast, cocaine has also been reported to impair human performance accuracy in a repeated acquisition task (Fischman, 1984).

Research from this laboratory as well has demonstrated that cocaine can simultaneously improve some aspects of behavior while impairing others. Cocaine improves reaction times, for example, in baboons trained to release a lever quickly when a stimulus occurs, i.e., when "detecting" stimulus onset (Hienz et al., 1993, 1994, 1995). Similarly, cocaine also shortens reaction times in baboons trained to release a lever when a stimulus *change* occurs, i.e., when "discriminating" a difference between stimuli (Hienz et al., 1995, 1996b). Additionally, cocaine's effects on reaction times appear to be independent of the type of stimulus signaling the response, since shortened reaction times fol-

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lowing cocaine have been demonstrated for both simple tones and white light stimuli in detection tasks (Hienz et al., 1993), and for simple tones and human speech sounds in a discrimination task (Hienz et al., 1994, 1995, 2002).

Such consistent effects are not as apparent, however, when one looks at cocaine's effects on performance accuracy in these tasks. For example, cocaine reduces performance accuracy in baboons discriminating among different speech sounds (Hienz et al., 1995) and among different tone pitches (Hienz et al., 2002), but does not affect the accuracy of *detecting* tones (Hienz et al., 1993, 1994). These results suggest that cocaine's motor effects may be fairly consistent across differing procedures and stimuli, but cocaine's perceptual effects may depend upon the type of behavioral procedure employed (i.e., detection vs. discrimination). The present report addresses this issue by examining the effects of cocaine under a procedure that simultaneously involves the detection of tones and discrimination of tone pitches. As in a detection task, baboons were trained to press and hold a lever down, and to release the lever only when a specific tone pitch of varying intensity occurred (i.e., to detect tone onset). The intensity of the tone was adjusted across trials to produce a psychometric function relating percent correct detections to stimulus intensity for estimating a detection threshold. Additionally, the procedure was modified so that on some trials a tone of a different pitch occurred, and animals were trained to withhold releasing the lever when this different tone pitch occurred (i.e., to "identify" the occurrence of a different tone pitch). The effects of cocaine on the accuracy of this combined identification/detection performance in baboons are contrasted with data from previous studies in which in baboons either identified or discriminated among speech sounds or tones of similar pitch (Hienz et al., 1995, 1996b, 2002). Additionally, reaction times to the stimuli were measured to assess whether cocaine had motor effects similar to those previously reported (Hienz et al., 1995, 1996a).

2. Method

2.1. Subjects

Three adult male baboons (*Papio anubis*) weighing between 25 and 33 kg served as subjects; two of the three baboons (DR and FR) were the same as those employed in previous studies of the effects of cocaine on the discrimination of speech sounds (Hienz et al., 1997) and the discrimination of tone pitches (Hienz et al., 2002). Each baboon was housed separately in a large primate cage equipped with a seating bench. All animals had auditory and visual contact with other baboons housed in the same colony room. The animals were maintained on a 22-h restricted feeding schedule with water continuously available in the home cage. Supplemental monkey chow and two pieces of fresh fruit were provided daily after each experimental session. The baboons were maintained on a daily 12-h light/dark cycle (6 a.m./6 p.m.). The experimental protocol for these studies was approved by an Institutional Review Committee for the use of animal subjects, and the procedures were in compliance with the National Institutes of Health Guide for Care and Use of Laboratory Animals.

2.2. Apparatus

The test cage was a modified primate squeeze cage placed inside a double-walled, sound-attenuating chamber (IAC, Model 1201A). A 76-cm-wide by 97-cm-high intelligence panel was attached to one side of the test cage and contained a red light-emitting diode as a cue light, a feeder opening for delivery of 500-mg banana-flavored pellets, and a primate lever (BRS/LVE Model PRL-003). With a baboon seated on a metal bench facing the panel, the cue light was at eye level, the feeder opening 25 cm below the cue light, and the response lever at waist level in front of the right arm. Each baboon was moved from his home cage to the test cage via a metal transfer cage. Stimulus presentations, response measures, and contingencies were controlled by Apple IIe computers.

2.3. Stimuli

Acoustic signals were pure tones of 1000 Hz (target tones) and 4000 Hz (standard tones), and were generated by a Coulbourn Instruments oscillator, passed through an electronic switch (20 ms rise/fall times) to eliminate possible clicks, to a programmable attenuator, and then to an amplifier. The amplified signals were sent inside the test chamber to a wide-range speaker located 20 cm above the ear level of a baboon's head as he sat inside the test cage. The system was calibrated with a General Radio sound level meter, a Bruel and Kjaer amplifier, and a 1.25-cm condenser microphone located at ear level facing the speaker. The tones employed thus differed considerably from the speech sound stimuli employed in previous studies (Hienz et al., 1995, 1996b), which consisted of synthetic vowel sounds ("aw" as in caught, "eh" as in let, "ah" as in lot, "ae" as in cat, and "uh" as in book) generated by an Echo II speech synthesizer.

2.4. Procedure

Baboons were trained to perform a reaction time task in which an animal held down a lever in response to a "ready" signal, and released the lever only when the 1-kHz target tone pitch occurred, but not when the 4-kHz standard tone pitch occurred (see Fig. 1). Additionally, the intensity of the target tone was varied from trial to trial so that estimates of an auditory threshold for the target tone could be obtained. The details of each trial are as follows: A trial commenced with a flashing red cue light (5/s) that served as the ready

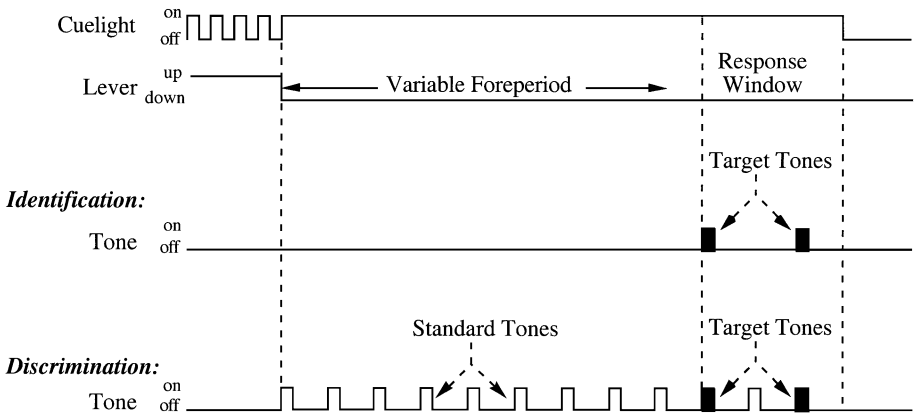

Fig. 1. Diagram of the relationships between stimuli and responses in a single trial for the present TID procedure and the previously employed TDS procedure. Under the identification procedure (middle), no background tone pulses occur as baboons hold the lever. Under the discrimination procedure (bottom), background tone pulses do occur as baboons hold the lever down. Under both procedures, baboons are rewarded for releasing the lever when a target tone occurs.

signal for pressing the lever down; the light flashed continuously until the lever was pressed. Once the lever was depressed, the cue light became steady and remained so as long as the animal held the lever down. Depression of the lever also initiated a variable lever-hold time, which consisted of a randomly selected time of from 1 to 7 s in duration, during which an animal was required to keep the lever down. At the end of this lever-hold period, a tone occurred for 120 ms, and was repeated again 1 s later (i.e., two tone bursts, 1 s apart). If the tone frequency was 1 kHz (target tone, probability of presentation=.80), a release of the lever within a response window of 1.5 s from the onset of the initial tone was considered a correct identification (“hit”) of the tone pitch, and was reinforced by immediate delivery of a 500-mg banana-flavored pellet. If the tone pitch was 4 kHz (standard tone, probability of presentation=.20), release of the lever during the 1.5-s response window was considered a “false alarm,” and was punished with a 15-s timeout from the experimental contingencies. A 4-s intertrial interval (ITI) followed either reinforcement or timeout, following which the start of the next trial was signaled by the flashing cue light. Failure to release the lever during the 1.5-s response window was defined as a “miss” if the target tone had been presented, and as a “correct rejection” if the standard tone had been presented. All failures to release the lever (i.e., both misses and correct rejections) resulted in the cue light being turned off to signal end of the trial, followed immediately by the ITI. During the ITI, lever responses reinitiated the ITI. Releases of the lever prior to the presentation of any tone (i.e., “early releases”) were also punished by a 15-s timeout.

Fig. 1 presents a diagram of the present procedure along with a diagram of the previously published tone discrimination (“TDS”) procedure (Hienz et al., 2002). As can be seen, the major difference between the present tone identification/detection (“TID”) procedure and the previous TDS procedure is the lack of a standard stimulus during the lever-holding period in the TID procedure. No background tone pulses occurred as baboons held the lever, and baboons were trained to simply release the lever only when they heard the 1-kHz target tone pitches. In the previous TDS procedure, baboons were trained to press and hold down a lever to produce a series of tone pulses, and to release the lever only when a *change* occurred in the pitch of the tone pulses (Fig. 1, bottom). These same two procedures have also been employed in previous studies that examined cocaine’s effects on the discrimination and identification of vowel stimuli by replacing the different tone pitches with different human vowel sounds (Hienz et al., 1995, 1996b). Thus, in the vowel discrimination (“VDS”) procedure, animals were trained to press and hold down a lever to produce a repeating vowel sound, and to release the lever only when the vowel sound *changed* to other vowel sounds. In the vowel identification (“VID”) procedure, no repeating vowel sound occurred as baboons held the lever, and baboons were trained to simply release the lever only when they heard specific target vowel sounds, but not when they heard a standard vowel sound.

2.5. Data collection and analysis

The TID sessions were 100 min in duration and occurred 5 days a week at approximately the same time each day. Each session was divided into blocks of 100 trials each. During this time, baboons typically performed five full blocks of trials, i.e., 500 identification/detection trials. Auditory thresholds were measured by randomly varying the intensity of the 1-kHz tone from trial to trial (method of constant stimuli) and examining detection frequencies (i.e., percent correct lever releases) at each intensity for each block of trials. Four intensity levels (10 dB apart) of the 1-kHz tone were used, with the lowest level set just below an animal’s estimated threshold. For each intensity of the target tone, the percent correct score for each block of trials was defined as the percentage of releases within the response window relative to the total number of trials presented for

that stimulus within each block of trials. False alarm rates were defined as the percentage of releases within the response window when the standard tone occurred, relative to the total number of standard tones presented within each block of trials. Reaction times to each comparison stimulus were timed from the onset of the first presentation of the stimulus to the release of the lever. Median reaction times for correct releases to each comparison stimulus were computed for each block of trials; medians of the reaction times were calculated because the physiological limits on reaction times can skew reaction time distributions. An auditory threshold was estimated from the percentage of correct detections at each intensity by interpolating to the intensity that produced a detection score halfway between the false alarm rate and 100% (Hienz et al., 1981).

Baseline performances were defined as stable when the following conditions were met: (1) the percentages of correct responses to the two loudest target tones were 90% or greater during all blocks in a session; (2) false alarm rates were less than 30% for all blocks of trials in a session; (3) median reaction times to the loudest target tone were within 50 ms of one another across all blocks in a session; and (4) there were no systematic changes in the time course of these measures across blocks within a session or across sessions. Because cocaine tended to shorten reaction times, the "maximal effect" of cocaine on reaction time values was calculated by selecting the shortest median reaction time from among the four to five blocks of trials of each drug session, and subtracting the mean of all blocks of median reaction times from the preceding day's saline control session. For comparison, estimates for reaction times following vehicle (saline) injections were calculated in an identical manner by selecting the shortest median reaction time from among the four to five blocks of trials of a vehicle session, and subtracting the mean of all blocks of median reaction times from the preceding day's vehicle session. These data analysis procedures were the same as those employed in the previous studies (Hienz et al., 1995, 1996b, 2002).

Changes in the accuracy of the performances were also assessed by examining changes in the signal detection index, d', as a function of drug dose. The d' index was calculated by transforming the percent correct (PC) scores and false alarm (FA) rates into proportions, converting them to z scores, and subtracting the FA z scores from the PC z scores ($d' = z(\mathrm{PC}) - z(\mathrm{FA})$; Macmillan and Creelman, 1991). Because z scores for the normal distribution cannot be calculated for proportions of 0 and 1, a method suggested by Macmillan and Creelman (1991) was employed to limit proportions so that near-zero values were no lower than $1/2N$, and values near 1 were no greater than $1 - (1/2N)$, where N is the number of trials employed in calculating the proportion. Estimates of the d' index following saline injections were calculated in an identical manner. For

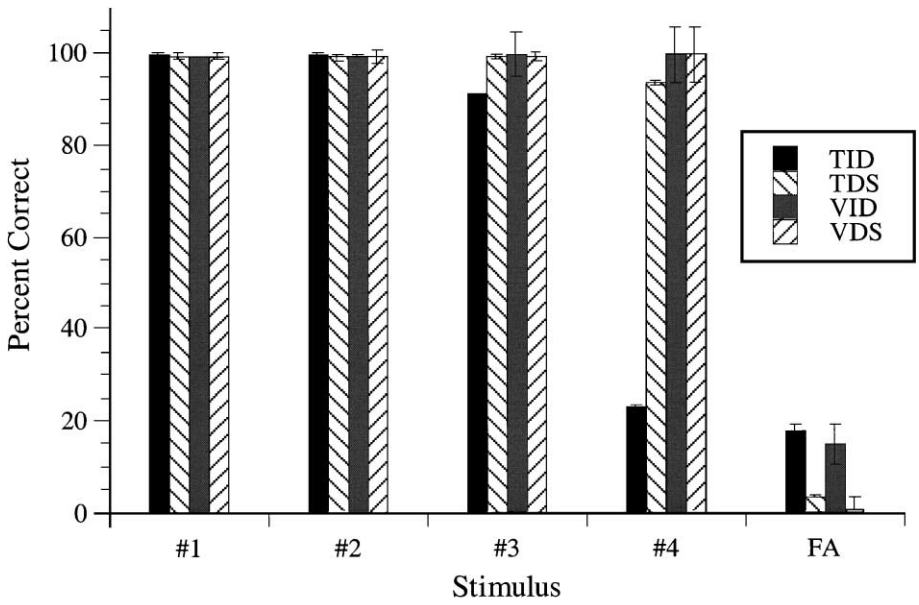

Fig. 2. Baseline identification performances averaged across all baboons, showing the percentage of correct detections ("hits") of the four indicated tones and vowels (1–4), and false alarm rates (FA) under the TID procedure, and under previous procedures of TDS, VDS, and VID. Error bars represent ±1 S.D.

comparison purposes, these same procedures were used to calculate d' values for data from the previous studies (Hienz et al., 1995, 1996b, 2002).

2.6. Drug administration

Cocaine and saline were administered intramuscularly in the gluteal region. Injections were given at approximately the same time each day, immediately before the session started. The actual injection site was varied from day to day to avoid tissue damage from frequent injections. Cocaine doses were administered once or twice weekly, typically on Tuesdays and/or Fridays. On all other days, 0.5 ml of NaCl vehicle was injected. All drug volumes were adjusted to be about 0.5 ml, with concentrations derived by dissolving drug in appropriate vehicle (0.9% sterile saline). Cocaine doses administered were 0.032, 0.1, 0.32, 0.56, and 1.0 mg/kg. The 1.0-mg/kg dose of cocaine produced cessation of responding in all subjects; consequently, no data are presented for this dose. Each dose was administered at least twice in mixed order, and additional doses were administered if there were large differences between first and second exposures at a dose. For baboon FR, a third dose was given at 0.032 and 0.32 mg/kg cocaine when one of the first two exposures at these doses fell outside the overall dose–effect function range for him and the other two subjects. Data on baseline performances (no drugs administered) were based upon the first 10 saline sessions after performance stability had been achieved, and typically covered the period during which the first one or two drug doses were administered.

3. Results

Fig. 2 presents a comparison of the average performance accuracy under the present TID procedure along with

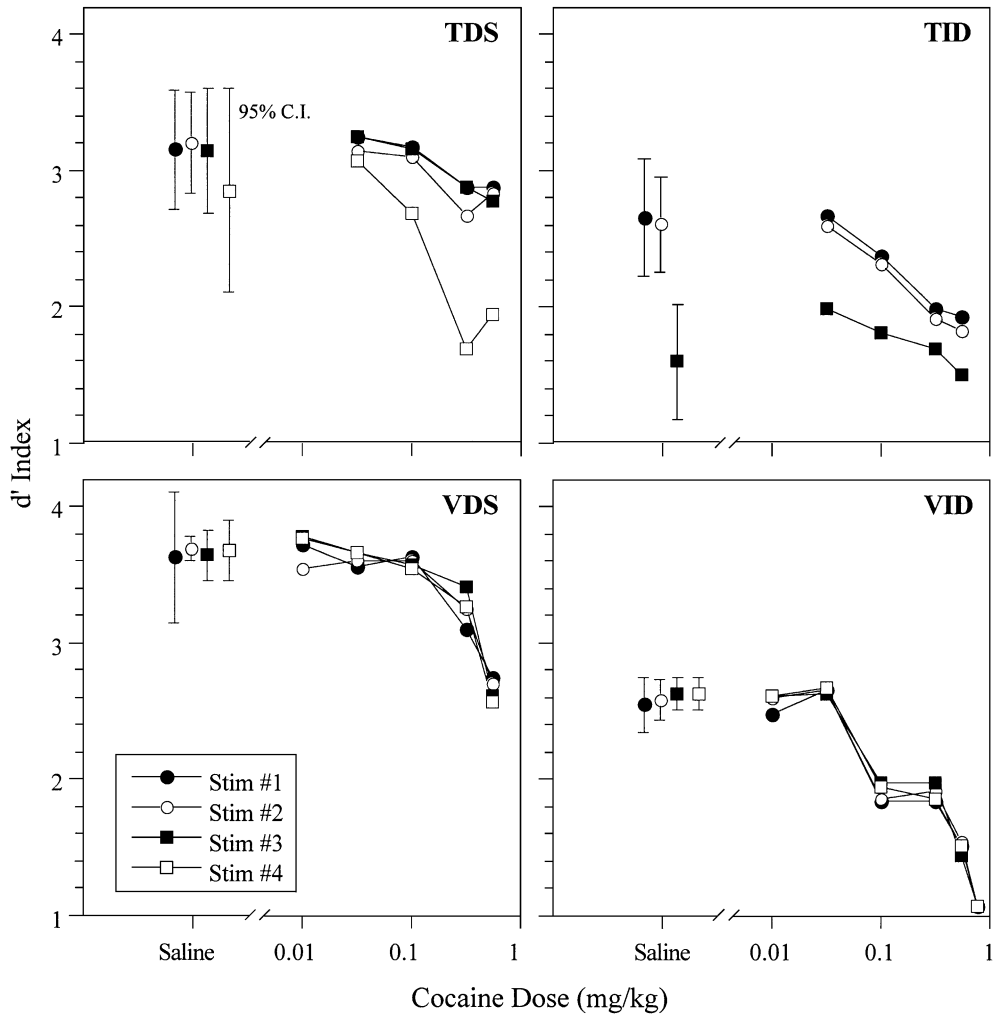

Fig. 3. Changes in the d' index of discriminability under the TDS, TID, VDS, and VID procedures as a function of cocaine dose. Error bars encompass 95% confidence intervals about the saline/vehicle points. TID cocaine doses administered were 0.032, 0.1, 0.32, and 0.56 mg/kg. TDS cocaine doses from a previous study were 0.032, 0.1, 0.32, and 0.56 mg/kg. VID cocaine doses from a previous study were 0.01, 0.032, 0.1, 0.32, 0.56, and 0.78 mg/kg. VDS cocaine doses from a previous study were 0.01, 0.032, 0.1, 0.32, and 0.56 mg/kg. Data are not shown for Tone 4 under the TID procedure since d' values for this below-threshold tone approximated zero (i.e., detection rates approximated false alarm rates).

previous accuracy data under the TDS, VID, and VDS procedures. Each bar represents the average performance for each of four stimuli across the first 10 saline sessions of each study. The actual stimuli employed under the four procedures are indicated below the *x*-axis. Despite the variety of stimuli employed, the performances under all four procedures were quite similar. Baboons performed at accuracies of 90% or higher for all four vowels under the VDS and VID procedures, and for the four tones under the TDS procedure. Under the present TID procedure, the average percent correct score (“hits”) for Tone 3 was slightly reduced, relative to the other procedures; for Tone 4, the average percent correct score was 23%, and thus approached the average false alarm rate under the TID procedure. This latter result was expected due to the fact that tone intensities were adjusted to produce psychometric functions, with Tone 4 being adjusted to be below the projected 50% detection threshold level. Baseline false alarm rates for both identification procedures (TID, VID) were higher than those for the discrimination procedures (TDS, VDS), and baboons showed slightly higher false alarm rates when responding to tones (TDS, TID), compared to vowels (VDS, VID).

Fig. 3 shows the dose-related effects of cocaine on the d' discriminability index for each of the four comparison tones under the identification procedure (TID), along with similar plots for tones under the TDS procedure and the four vowels under the VDS and VID procedures. Each point represents the average of three baboons at each stimulus, with error bars encompassing ±95% confidence intervals about the baseline saline points. Points falling outside of the 95% confidence intervals are thus significantly different (P=.05) from baseline performances. Data are not shown for Tone 4 under the TID procedure since d' values for this below-threshold tone approximated zero (i.e., detection or “hit” rates approximated false alarm rates). As can be seen in Fig. 3, the d' discriminability index under baseline (saline) conditions varied across procedures, with the average baseline discriminability higher under the discrimination procedures (VDS, TDS) than under the identification procedures (VID, TID), and higher for vowel stimuli (VDS, VID) than for tone stimuli (TDS, TID). These results parallel those shown in Fig. 2 for baseline percent correct scores.

Differences in cocaine’s dose–effect functions were also apparent across the various procedures. Under the TDS and TID procedures, dose-related reductions in tone discriminability occurred following cocaine (upper graphs), and appeared related to the stimulus characteristics. Under the TDS procedure, only Tone 4 showed significant decreases in discriminability at the higher cocaine doses. Under the TID procedure, significant decreases in discriminability at the higher cocaine doses were seen for Tones 1 and 2, but not for Tone 3. On the other hand, dose-related reductions in vowel discriminability occurred for all vowel stimuli under both VDS and VID procedures following cocaine (lower graphs), and the relative magnitudes of these reductions (i.e., relative changes in d') were about the same for both procedures when compared across the same dose range (0.01–0.56 mg/kg). When dose–effect functions for changes in thresholds under the TID procedure were examined, no significant changes were seen following cocaine (data not shown). Corroborating evidence of this lack of effect of cocaine on threshold detectability can be seen in the lack of a significant change in the d' index for Tone 3 under the TID procedure (Fig. 3, top right), and the fact that no changes in the d' index occurred for Tone 4 as well (data not shown; d' values were approximately 0.0 for both saline and all drug doses for Tone 4, indicating no discriminability above chance levels for this below-threshold tone).

Fig. 4 shows the changes in false alarm rates as a function of cocaine dose under the four different procedures. Clearly, cocaine was most effective in elevating false alarms under both identification procedures (TID, VID), and produced relatively modest elevations under the discrimination procedures (TDS, VDS). At 0.32 mg/kg, the highest cocaine dose for which data were obtained under all four conditions, false alarm rates were raised by about 25–30% relative to baseline levels under the identification procedures. In contrast, under the discrimination procedures, the same dose produced less than a 10% increase in false alarms, relative to baseline.

Fig. 5 shows the dose-related effects of cocaine on reaction times under the four different procedures. The data shown are averages across three baboons for each comparison stimulus and shows the “maximal” effect of cocaine in reducing reaction times for vowels and/or tones. To make comparisons across procedures, reaction times under the TID procedure are shown for the loudest stimulus only

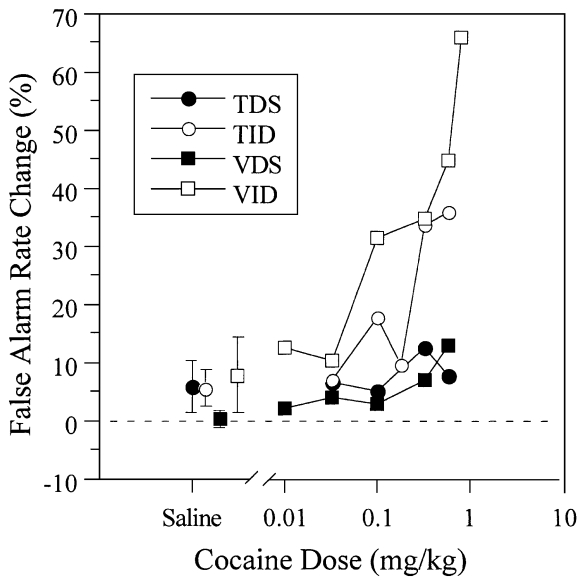

Fig. 4. Average false alarm rates under the TDS, TID, VDS, and VID procedures as a function of cocaine dose. Error bars encompass 95% confidence intervals about the saline/vehicle points. Further description as in Fig. 3.

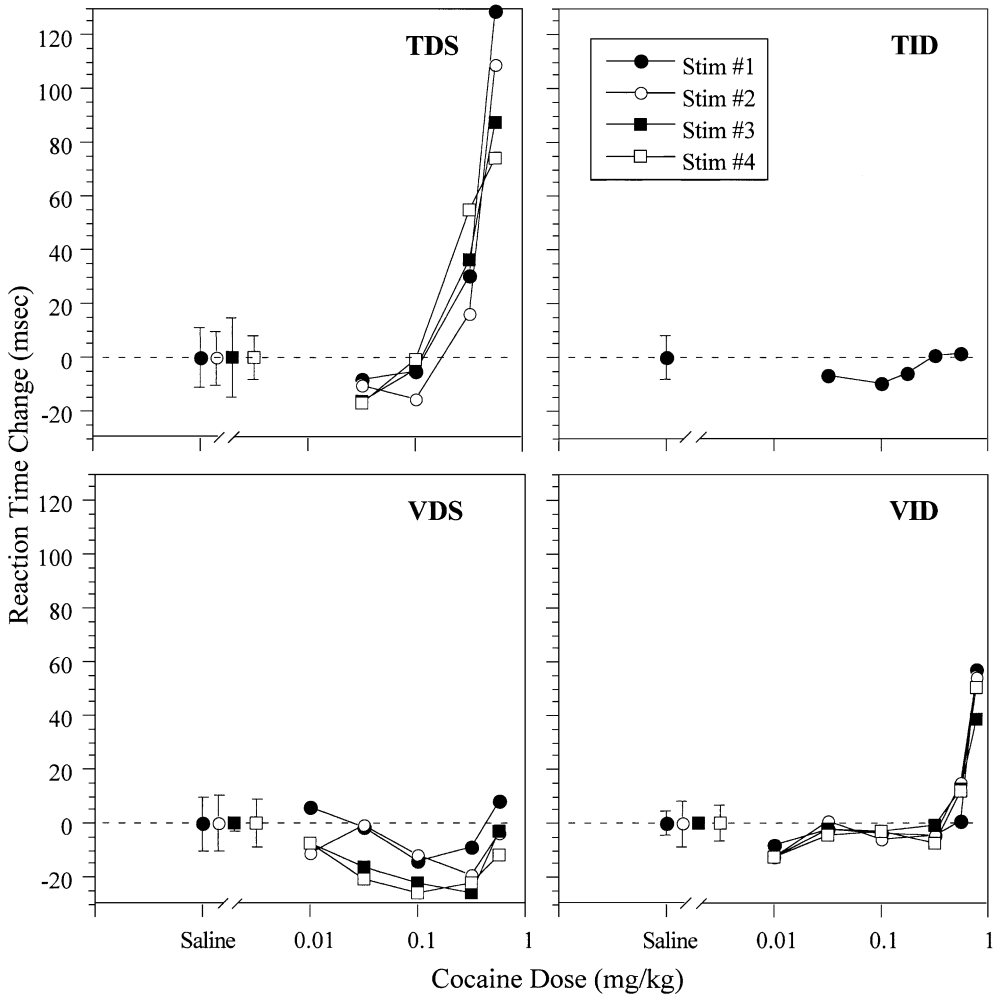

Fig. 5. Changes in reaction times at the time of peak drug effect under the TDS, TID, VDS, and VID procedures as a function of cocaine dose. Error bars encompass 95% confidence intervals about the vehicle points. Further description as in Fig. 3.

(Tone 1), since reaction times lengthen and become highly variable as a sound's intensity nears threshold values (Pfingst et al., 1975). Under the different procedures, different shapes occurred for the dose–effect functions relating changes in reaction time to cocaine dose. One common feature under all procedures, however, was that at the lower cocaine doses, reaction times were significantly shortened, whereas at the higher cocaine doses, reaction times either returned to saline baseline levels (TID, VDS) or were elevated above baseline levels (TDS, VID). These differences in the dose–effect functions were not apparently related to the stimulus conditions (tones vs. vowels) or the procedure employed (discrimination vs. identification).

4. Discussion

The results of the present study show clearly that cocaine can produce dose-related impairments in tone discriminability as defined by the d' index, and thus replicate previous findings of impairments in discrimination accuracy following cocaine when baboons are discriminating between different speech sounds (Hienz et al., 1995) and different tone pitches (Hienz et al., 2002), and identifying different speech sounds (Hienz et al., 1996b). Overall, these findings suggest that, qualitatively, cocaine produces similar impairments in these various types of auditory perceptual discriminations. The manner in which cocaine impairs performance accuracy, however, appears to differ depending upon both the type of discrimination procedure employed (discrimination vs. identification) and the stimuli being discriminated (tones vs. speech sounds).

4.1. Drug effects associated with procedural differences

A number of differences between both the baseline performances and the cocaine-induced performance changes of the four auditory discrimination procedures suggest that a major factor in the perceptual effects produced by cocaine is the type of procedure employed. First, under both the TID and VID procedures, baseline false alarm rates were higher and d' values were lower, compared to the discrimination

procedures. These results indicate that the two identification procedures were more difficult to perform than the two discrimination procedures. Second, cocaine lowered the d' index of discriminability more so under the VID than the VDS procedure, indicating a greater drug effect under the more difficult procedure. Third, cocaine raised false alarm rates significantly under the identification procedures but had little effect on false alarm rates under the discrimination procedures, again suggesting a greater drug effect for the more difficult procedure. Finally, d' values following cocaine under the identification procedures often approached a value of 1.0, which is a typical cutoff value for threshold levels of discriminability (Macmillan and Creelman, 1991). Thus, under the identification procedures, the impairments produced by cocaine approached the point at which acoustic stimuli are no longer reliably discriminated. Taken together, these results indicate that the effects of cocaine on perception can be critically dependent upon not only the type of perceptual processes being examined, but also the relative "difficulty" or degree of stimulus control evidenced in the discrimination procedures employed. The present findings thus lend further support to the suggestion by Katz (1990) that the magnitude of a drug's effects upon stimulus control may be inversely related to the initial level of stimulus control.

The differences in both baseline performances and cocaine's effects on performances under the identification vs. discrimination procedures are most likely due to differing stimulus presentation contingencies. On one hand, in the discrimination procedure, a lever hold produces a series of pulses of a standard stimulus, with the discriminative stimulus for lever release being a change to one of four "comparison" stimuli. Only lever releases within the 1.5-s response window following this stimulus change are reinforced, and lever releases in the absence of a stimulus change (i.e., during catch trials) are punished with a brief timeout. Given these contingencies, one would expect that in the absence of a clearly detectable stimulus change, a subject would most likely continue holding the lever down, since the probability of reinforcement following a random lever release under this procedure is .22, whereas the probability of a timeout following a random lever release is .78 (Hienz et al., 1996b). On the other hand, in the identification procedure, a lever hold does not produce a series of pulses of a standard stimulus. Instead, a successful lever hold results in a stimulus presentation that signals the start of the 1.5-s response window, and the subject then either releases or continues to hold the lever down, depending upon the stimulus presented. Given these latter contingencies, a lever release to any given stimulus presentation would result in 80% of the responses being reinforced, (i.e., only 20% of the trials are catch trials). These latter contingencies would be expected to increase lever releases following any stimulus onset, and thus elevate the frequency of both false alarms and correct identifications. In the present study, baseline false alarm rates under both the TID and VID procedures were considerably higher than under the TDS and VDS procedures. While no reliable differences in percent correct scores were observed between the identification and discrimination procedures, this may be due to a ceiling effect of most of the stimuli being easily discriminated, regardless of the procedure.

Hienz et al. (1996b) previously noted that cocaine's effects under these two different procedures may be viewed as producing a bias towards more frequent lever releases. This interpretation was based on the fact that the bias occurred only when a stimulus was actually presented, whereas early lever-release rates were not affected by cocaine. This effect of cocaine upon stimulus control could result from a reduction in stimulus discriminability, as previously noted by Hienz et al. (1995), or result from a slight loss of stimulus control, i.e., a reduction in the effectiveness of the contingencies of reinforcement for incorrect responses. However, Hienz et al. (1996b) also noted that subjects showed small decreases in percent correct detections as a function of cocaine dose, suggesting that cocaine likely also lowers stimulus discriminability. In the present case as well, the observed decreases in discriminability as measured by the d' index were not solely attributable to elevations in false alarm rates, but also due to decreases in percent correct scores as well.

4.2. Drug effects associated with stimulus differences

Performance differences among the four procedures also suggest that the perceptual effects produced by cocaine vary as a function of the type of stimuli employed. First, baseline false alarm rates were higher and baseline d' values were lower for tone discriminations, indicating that the tone discriminations were more difficult than were the speech sound discriminations. Second, cocaine's effects on these discriminations indicate that the tone stimuli were differentially affected following cocaine, whereas the vowel stimuli appeared to be affected to about the same degree—a result that occurred in spite of the tone stimuli being selected to approximate the naturally occurring changes in the second formants of the vowels. Comparatively speaking, however, the vowels employed are much more rich in acoustic features (e.g., variations in formants, fundamental pitch, etc.) that can serve as cues to aid in discrimination, so it is not surprising that the 1.23-kHz tone pitch showed a much greater drug effect than did the corresponding vowel "eh" in the discrimination tasks. It is important to note that previous data have shown cocaine's effects on vowel discriminations to be inversely related to the discriminability of the vowels (Hienz and Brady, 1989; Hienz et al., 1995). Thus, the more similar a comparison vowel is to the standard vowel, the greater the drug effect observed. These differences were observed within individual subjects, however, and not in the averaged data. This is because individual subjects can and do attend to different cues within vowels; e.g., in a previous study, one baboon

attended consistently to changes in the first formant, while another baboon attended to changes in the second formant (Hienz and Brady, 1988). Such effects are thus not apparent in the averaged data presented in Fig. 3.

The effects of a number of drugs of abuse, including cocaine, have been documented in threshold detection tasks for both auditory and visual stimuli; these studies have shown that cocaine impairs visual thresholds but not auditory tone thresholds (Hienz et al., 1993, 1994). Thus, the effects of cocaine on these performances can be quite modality-specific, given identical behavioral procedures. In such a case, one can rule out the possibility of any overall changes in motivation or in general performance produced by cocaine. Additionally, drugs such as diazepam, cocaine, and Δ-9-THC (the main psychoactive ingredient in marijuana) impair the perception of vowel sounds, but the effects of these drugs on speech sound discriminations are not attributed to a general decrement in overall performance since the drugs differentially affect other aspects of the discriminations (Hienz and Brady, 1987, 1988, 1989; Hienz et al., 1995). For example, diazepam lengthens reaction times to the stimuli, whereas cocaine shortens reaction times and Δ-9-THC does not affect reaction times. Finally, changes in motivation are minimized in self-paced procedures such as the RT procedure, since animals must make an "observing response" (depress the lever) to initiate each trial. Typically, either animals initiate trials and complete them, or they do not initiate trials at all (e.g., at extremely high drug doses). Further, no changes were observed in pellet intakes or in reaction time latencies across sessions. Consequently, data obtained under the RT procedure are relatively free of possible motivational changes related to food reinforcement.

4.3. Drug effects on reaction times

In the present study, cocaine produced minimal decreases in reaction times, compared to those reported previously for tone threshold and vowel discriminations tasks (Hienz et al., 1993, 1994, 1995). For example, acute administration of cocaine decreases reaction times by about 10–30 ms in a tone threshold procedure (Hienz et al., 1993), and by 50–80 ms in a vowel discriminations procedure (Hienz et al., 1995). The lack of comparable reaction time reductions in the present study is likely due to procedural differences. As noted previously (Hienz et al., 1996b), the identification procedure is similar to a human choice reaction time procedure in that a subject responds to one stimulus but not to a second (Luce, 1986), while both tone threshold and the vowel discriminations procedures are variants of a simple human reaction time procedure in that a subject responds to all stimuli. In a human choice procedure, reaction times are typically 100–150 ms longer than in a simple reaction time procedure, presumably due to added decision processing time (Luce, 1986). The minimal effects of cocaine on the present choice reaction times may thus be a function of the differences in the performance complexity or difficulty underlying responding in the reaction time task. The fact that minimal effects of low doses of cocaine on reaction times were observed in the VID procedure lends added support to this possibility. On the other hand, similar cocaine dose–effect functions occurred for reaction times under the TDS and VID procedures. Thus, there does not appear to be a consistent effect of procedure type in influencing cocaine's effects on reaction times. Similarly, no consistent differences were apparent as a function of the type of stimuli being identified/discriminated.

In summary, the results of the present study show clearly that cocaine can impair the discriminability of tone pitches in baboons, and that such impairments in acoustic perception are qualitatively similar to those previously demonstrated effects of cocaine on the discrimination of tones and the discrimination and identification of speech sounds. The manner in which cocaine produces these disruptions in auditory perception, however, can vary as a function of the difficulty of the procedure employed (discrimination vs. identification), and the discrimination difficulty of the stimuli employed (tones vs. speech sounds) to assess perceptual function.

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