J Clin Pharmacol. 1981; **21**:299S–310S.

Effects of Moderate and High Doses of Marihuana on Thermal Pain: A Sensory Decision Theory Analysis

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Abstract: Sixteen habitual marihuana users, selected for their good mental and physical health, were hospitalized for three months in the New York State Psychiatric Institute. During the first month, the subjects were drug free; during the second month, they smoked marihuana cigarettes provided by NIDA (2% THC, 20 mg per cigarette) at the rate of 3 to 12 a day. A modified Hardy-Wolff dolorimeter was used to present 20 thermal stimuli of 30-second duration in a random manner at nine different intensities. Subjects responded from a 14-category scale, and data were analyzed according to sensory decision theory analysis. During the third month, the subjects were again drug free. At the noxious thermal intensities, there was a decrease in the pain report criterion during the first two weeks of smoking. The pain enhancement effect was followed by return to the presmoking pain level during weeks 3 and 4 and in the postsmoking period, indicating that tolerance had developed. There was also an increase in pain discriminability during the four weeks of smoking which extended for one week after smoking. Tolerance developed to the pain report criterion but not to the thermal discriminability. This study suggests that marihuana may have hyperalgesic activity and probably enhances the perception of pain, in moderate smokers. In contrast, heavy smoking had little effect on discriminability and caused an increase in the pain report criterion.

THE evaluation of possible analgesic properties of psychoactive substances which possess marked mood-altering characteristics presents a particularly difficult problem, since a change in pain threshold could be caused by mood changes even in the absence of analgesia. It is well known that the report of pain is strongly influenced by psychological variables: personality, cultural factors, anxiety, mood, etc. There is no evidence that these changes in reported pain necessarily reflect a change in subjective sensation. Thus, a raised pain threshold following the administration of a psychoactive drug, such as marihuana, may be misinterpreted as analgesia when it is merely the result of euphoria or reduced anxiety. In a reply to Ominsky,[1] Clark and Yang[2] emphasized that when psychotropic and analgesic effects are mixed, only the sensory decision theory (SDT) model offers the possibility of a solution. A mathematical introduction to parametric SDT as applied to pain has appeared,[3] and a simple introduction to the nonparametric model is presented in the Appendix.

Sensory decision theory dissects the traditional perceptual threshold into two indices of observer performance. The sensory measure, $P(A)$ or d', employs error rate to estimate discriminability among stimuli of various intensities; it reflects neurosensory function and is uninfluenced by psychological variables such as expectation. Known analgesics such as morphine[4] have been shown to decrease $P(A)$, presumably because the amount of sensory information

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reaching higher centers is attenuated. The other SDT parameter, the report criterion, B or L_x, locates the subject's criterion for reporting pain, that is, his tendency to report or deny the presence of pain, a result of suggestion, anxiety, or attitude. A series of studies by Clark and associates have shown that the pain report criterion can be altered by a placebo, various instructions, age, ethnicity, etc., without influencing the discriminability index.[5,6] Sensory decision theory was used by Yang et al.[4] to isolate analgesic effects from affective changes. They demonstrated that although both morphine and diazepam raised the pain threshold to thermal stimulation, the underlying reasons differed. Treatment of the data by sensory decision theory revealed that morphine markedly decreased discriminability, $P(A)$, an analgesic effect, and also raised the pain report criterion, B, a report bias effect. In contrast, the raised pain threshold induced by diazepam was mostly due to an increase in the pain report criterion, B, a psychological effect produced by its anxiolytic properties. In addition, a relatively small but significant decrease in discriminability, $P(A)$, indicated that diazepam possesses analgesic properties.

The purpose of the present study was to examine the effect of different levels of marihuana smoking on discriminability, $P(A)$, and pain report criterion, B, measures of sensory decision theory. We hoped that this approach would illuminate the rather confused literature concerning the possible analgesic effects of the cannabinoids. A preliminary analysis of the data has appeared.[7] In the present study, the effects of high and low levels of consumption are examined, and the posttest data are treated in greater detail. In addition, the report is made more comprehensible by presenting the discrimination results as $P(A)$ instead of $2 \sin^{-1} (\sqrt{P(A)})$.

Folklore surrounding the use of various preparations of *Cannabis sativa* suggests that they possess analgesic properties. Some studies with animals support this belief. However, the dose levels used tend to be high, and it is difficult in animals to distinguish drug effects on pain responses from those which merely influence motor responses. A more direct approach is to study the effect of drugs on the verbal response to noxious stimulation in human volunteers. Few such studies have been undertaken, and these have yielded conflicting results. A double-blind study by Milstein, MacCannel, Karr, and Clark[8] showed a significant increase in pain tolerance among those who had smoked marihuana. Noyes, Brunk, Baram, and Canter[9] studied cancer patients who were given Δ^9-tetrahydrocannabinol (THC) in 5- to 20-mg doses or placebo. Pain reduction was greater than with placebo at both THC levels. The difficulty with classical threshold studies of experimental pain is that the pain threshold is influenced by both expectation and analgesia. It is well known that subjects who believe that they have received an analgesic will show a raised pain threshold.[10] The "double-blind" control does not solve this problem, since subjects may be able to distinguish between the placebo and the drug condition on the basis of subjective effects such as euphoria, clouding of consciousness, etc.

Other investigators have failed to find that THC induced analgesia. For example, Harris[11] was not able to confirm the analgesic effect of THC using standard analgesic test procedures. Hill, Schwin, Goodwin, and Powell[12] studied the pain thresholds to cutaneous electrical stimulation in male volunteers by the method of limits. The dose was approximately 12 mg THC. In contrast to those who reported analgesia or no effect, they found that the marihuana actually decreased the pain threshold, that is, made the subject more sensitive to painful stimulation. This result is consistent with reports of heightened sensitivity or "perceptual sharpening" produced in other sensory modalities by marihuana. However, they insightfully noted that the decrease in threshold may have been caused

not by drug-induced physiologic changes but by the subject's expectation that pain sensitivity would be enhanced by marihuana.

Earlier studies may be criticized on three grounds: the dose was acute rather than chronic; the dose may not have been high enough; and the psychophysical procedures used yielded a pain threshold, which is a mixture of sensory and attitudinal variables. Since dose level may be an important cause of the discrepancies reported in the literature, in the present report we have divided the subjects into moderate and high dose groups for a detailed analysis.

According to sensory decision theory, if marihuana is an analgesic, it should decrease discriminability $P(A)$ and raise the pain report criterion B. If there is only a change in mood, then B might be altered without a change in $P(A)$. On the other hand, if marihuana enhances pain perception, $P(A)$ may be increased and B lowered.

Methods

Males who were regular marihuana users, age 18 to 30 years, were admitted to the Drug Abuse Research Ward of the New York State Psychiatric Institute. Their marihuana use ranged from one to two cigarettes every few days to six cigarettes daily. Subjects using other drugs except for tobacco and moderate amounts of alcohol or who were in psychotherapy were excluded. Another reason for exclusion was recent viral infection such as hepatitis or mononucleosis, which would have interfered with the biological portion of the study (these studies have been reported elsewhere[13]). The subjects were restricted to the ward for the duration of the experiment. When the necessity arose for subjects to leave the hospital, they were accompanied by hospital staff members. Thus, the possibility of use of other drugs throughout the experimental period was negligible. The 14 subjects were paid for participating in the study, and signed an informed consent form.

The experiment was divided into three parts: "washout" period, three to four weeks; smoking period, four weeks; and postsmoking "washout" period, three to four weeks. At the end of the washout period, subjects began smoking marihuana cigarettes provided by the National Institutes of Health, standardized at 2 per cent content of THC (20 mg per cigarette). Smok-

TABLE I

Mean Number of Marihuana Cigarettes (20 mg THC) Smoked by Moderate-and High-Consumption Groups

Day	1	2	3	4	5	6	7	Daily average each week
Moderate	1.0	1.1	2.3	2.4	3.6	3.6	4.8	2.7
High	1.6	2.6	4.3	4.1	6.0	6.6	7.6	4.7
Day	8	9	10	11	12	13	14	
Moderate	7.0	7.9	7.7	8.9	8.7	8.4	9.2	8.2
High	9.7	13.3	13.3	11.1	12.7	12.0	15.6	12.5
Day	15	16	17	18	19	20	21	
Moderate	12.6	10.1	12.1	9.0	13.0	12.3	13.6	11.8
High	14.4	14.8	21.1	14.6	17.0	17.1	26.0	17.9
Day	22	23	24	25	26	27	28	
Moderate	11.9	10.3	12.7	15.9	12.6	11.7	16.9	13.1
High	22.9	13.3	18.0	22.4	14.7	18.3	25.9	19.4

TABLE II

Relationship Between Response Bias Values *B* and the Response Category Scale*

Values of *B*																				
14	13	12	11	10	9	8	7	6	5	4	3	2	1							
Nothing	Maybe something	Faint warmth	Warm	Hot	Very hot	Very faint pain	Faint pain	Pain	Very painful					Withdrawal times (sec)						
														2.66	2.32	2.00	1.99			
														3.00	2.65	2.31				

* Only the verbal categories, "nothing" to "very painful", appeared on the scale given to the subject. A high value of *B* occurs when there are few reports of pain. See Appendix.

ing proceeded by increments of approximately one cigarette each day until a total of 10 cigarettes had been reached, and then the subjects were at liberty to smoke as many cigarettes as they wished. The subjects smoked an average of 3.7, 10.4, 14.5, and 16.5 cigarettes per day during the first, second, third, and fourth week of smoking. Details of cigarette consumption appear in Table I. Both groups consumed a large number of cigarettes. The mean for the high consumption group was 384 ± 19.7 S.E. cigarettes, and for the moderate group, 250 ± 23.5 S.E., the average per day being 13.7 and 8.9 respectively.

The subjects were administered the pain test approximately every one to two weeks. They smoked one cigarette immediately before being tested. A modified Hardy-Wolff dolorimeter was used to present 20 thermal stimuli, in a random manner, at each of the following intensities: 0, 45, 90, 135, 180, 225, 270, 315, 360, and 405 mcal/sec/cm^2. The stimuli were 3.0 seconds in duration (unless the subject withdrew sooner) and 2 cm in diameter. The subject responded from a verbal category scale (see Table II) which ranged from "nothing" through various degrees of "warmth," "heat," and "pain" to "very painful." The number of each category and the withdrawal times are for subsequent discussion and were not on the scale presented to the subject.

Results

Analyses of variance (ANOVA) were performed separately for discriminability $P(A)$ and report criterion B. Values of $P(A)$ represent the area under the receiver-operating-characteristic (ROC) curve, a plot of hit rates against false affirmative rates, and range from perfect discrimination, 1.0, to chance performance, 0.5 (see Appendix). For thermal discriminability $P(A)$, the most important finding was a significant session-by-group interaction $F = 2.98$, $df = 4,48$, $P < 0.03$. As portrayed in Table III, during weeks 3 and 4 of smoking, $P(A)$ for

TABLE III

Mean Thermal Discriminability $P(A)$ by Sessions for Moderate and High Consumers

Amount consumed	Session				
	Presmoking	Smoking weeks 1,2	Smoking weeks 3,4	Post-1	Post-2
Moderate	0.69	0.70	0.72*	0.73*	0.73*
High	0.71	0.69	0.68*	0.69	0.70

* Significantly different from presmoking session, $P < 0.05$.

the moderate consumers increased while $P(A)$ for the high-consumption smokers decreased. During the postsmoking sessions, $P(A)$ for the moderate smokers remained high, while $P(A)$ for the high-consumption smokers returned to initial levels. According to a post-hoc Tukey Honestly Significant Difference test (HSD), $q(5) = 4.04, df = 48, P < 0.05$, for a critical difference ≥ 0.03.

As shown in Table IV, the ANOVA also revealed a main effect for intensity $F = 10.18$, $df = 8.96$, $P < 0.001$; the higher-stimulus intensities (with the exception of 360 to 405 mcal, where the responses were withdrawals) tended to be more discriminable for a constant separation of 45 mcal between the pairs of stimuli. The session-by-stimulus intensity interaction ($F = 1.84$, $df = 32,384$, $P < 0.004$) was caused by discriminability among the lower-intensity stimulus pairs from 0-45 to 180-225, remaining relatively constant over sessions, while $P(A)$ at the painful intensities, 225-270 and above, tended to increase during weeks 3 and 4 of smoking, as well as during the two postsmoking sessions, HSD test, $q(9) = 4.39$, $df = 384$, $P < 0.05$, for a critical difference ≥ 0.09.

The report criterion measure B locates the rating scale criterion at which half of the responses are to the higher response categories and half are to the lower. A high value indicates a stoical criterion, few pain reports; a low value, the opposite. A criterion of 8.5 is set at the "very faint pain" category (further details appear in the Appendix). As portrayed in Table V, ANOVA for report criterion B revealed a significant triple interaction for session-by-group-by-intensity ($F = 3.49$, $df = 32, 384$, $P < 0.001$).

TABLE IV

Mean Thermal Discriminability $P(A)$ for Adjacent Pairs of Stimulus Intensities

Stimulus intensity (mcal)	Session				
	Presmoking	Smoking weeks 1,2	Smoking weeks 3,4	Post-1	Post-2
0-45	0.72	0.68	0.71	0.67	0.71
45-90	0.74	0.66	0.66	0.70	0.68
90-135	0.62	0.66	0.63	0.60	0.64
135-180	0.68	0.69	0.67	0.69	0.67
180-225	0.70	0.66	0.67	0.72	0.67
225-270	0.71	0.78	0.78	0.73	0.78
270-315	0.73	0.77	0.79	0.83	0.80
315-360	0.71	0.73	0.70	0.77	0.78
360-405	0.66	0.65	0.68	0.71	0.68

TABLE V

Mean Report Criterion *B* for Moderate and High Consumers

Stimulus intensity (mcal)	Amount consumed	Session				
		Presmoking	Smoking weeks 1,2	Smoking weeks 3,4	Post-1	Post-2
0-45	Moderate	12.9	12.9	13.0	13.1	13.1
	High	13.0	12.8	12.8	13.1	13.2
45-90	Moderate	12.0	12.3	12.2	12.2	12.4
	High	12.3	12.3	12.3	12.6	12.5
90-135	Moderate	11.2	11.6	11.7	11.6	11.8
	High	11.4	11.7	11.6	12.0	12.0
135-180	Moderate	10.4	10.8	11.3	11.0	10.9
	High	10.9	11.0	10.8	11.4	11.4
180-225	Moderate	8.8	9.8	10.3*	10.0*	9.8
	High	10.0	10.3	9.9	10.5	10.8
225-270	Moderate	6.6	8.3*	8.9*	8.1*	8.5*
	High	7.9	8.5	7.6	9.6*	10.1*
270-315	Moderate	5.8	5.8	5.5	4.5*	4.3*
	High	5.7	5.4	5.2	7.1*	8.1*
315-360	Moderate	4.7	3.3*	3.4*	2.5*	2.6*
	High	4.4	3.5	3.4	5.0	5.6*
360-405	Moderate	3.6	2.3*	2.2*	1.7*	1.8*
	High	3.0	2.8	2.8	3.5	3.7

* Significantly different from presmoking session, $P < 0.05$.

According to the HSD test, $q(5) = 3.86$, $df = 384$, $P < 0.05$, for a critical difference ≥ 1.2. This interaction was caused by differences in criterion values at different stimulus intensities between moderate and heavy smokers over the various sessions. Compared to the presmoking session, at the three highest intensities, moderate smokers tended to lower their criteria during both the smoking and posttest periods. For example, at stimulus intensities of 315 to 360 mcal, the moderate smokers lowered their criterion from the presmoking level of "very painful," no withdrawal (4.7), to a criterion of "very painful," withdrawal in approximately 2.50 seconds (3.3) during smoking, and still further to 2.25 seconds (2.6) during the postsmoking sessions. In contrast, the heavy smokers did not change significantly until the last session when they raised their criterion, that is, they found that the stimuli, although still perceived as painful, no longer forced a withdrawal. In contrast to the high intensities, the criteria for the lowest four pairs of intensities, "maybe something" to "hot," showed no change over sessions for either group of smokers.

Discussion

Moderate smokers demonstrated a somewhat clearer shift in pain perception than did the heavy smokers. For the moderate smokers, discriminability among the noxious thermal stimuli increased during smoking, especially during weeks 3 and 4, relative to the presmoking period; this effect persisted during the postsmoking sessions. The pain report criteria for moderate smokers showed a decrease (more reports of pain) during both of the smoking and both of the postsmoking sessions. The combination of increased discriminability $P(A)$ and decrease in the pain report criterion B found

in the moderate group of smokers indicate that pain was enhanced. These results are congruent, since increased discriminability suggests that more information was reaching higher centers, and the decrease in *B* means that more pain responses were given. Thus, the results obtained with the moderate smoking group support the view that at certain dose levels chronic marihuana smoking enhances pain, and that this effect apparently persists for at least three to four weeks. Messing and Lytle[14] have summarized a large number of studies which support the hypothesis that reduction in brain or spinal cord serotonergic neurotransmission is associated with increased sensitivity to noxious stimulation. The report by Taylor and Fennessy[15] that brain levels of serotonin are reduced in rats after five days of THC administration is congruent with our findings of increased discriminability and lowered pain report criterion.

Although the increase in $P(A)$ suggests hyperalgesia, hyperalgesia is not the only possible source of a decrease in *B*; attitudinal factors could also play a role. An increase in pain report is consistent with "perceptual sharpening" reported in other sensory modalities, such as vision, hearing, and taste, as well as with comments from our subjects that they never smoked marihuana while suffering a headache or toothache because it would increase the pain. We also noticed that the subjects did not smoke before being venipunctured for blood samples, a procedure which they found very painful. If our group of moderate smokers expected pain enhancement, this alone could have lowered the pain report criterion. The opposite expectation, that there would be less pain following marihuana smoking, could readily raise the pain report criterion and falsely suggest an analgesic effect. In contrast to our subjects who expected sensory enhancement, patients suffering clinical pain are particularly ready to believe that a new treatment should be helpful and ameliorate pain. Thus, the reputed analgesic effect of marihuana in patients suffering cancer pain reported by Noyes et al.[9] could be due to placebo effects, to euphoria, or, in the instance of patients receiving chemotherapy, to increased well-being which results from the antiemetic effect of marihuana.[16] Expectation could also explain the increase in pain tolerance reported by Milstein et al.[8]; the use of the double-blind control is not sufficient, since psychotropic effects of marihuana permit the subject to "peek through the double-blind." The heavy smokers behaved in an opposite manner to the moderate smokers. During weeks 3 and 4 of smoking, they showed a decrease in discriminability relative to their presmoking period. This decrease could suggest an analgesic effect according to the SDT; however, this seems doubtful in view of the fact that pain reports did not decrease, that is, the pain report criterion was not raised.

The triple-order interaction showed that while the moderate smokers had a lower criterion (more pain reports) during the postsmoking sessions—a result congruent with their low $P(A)$—the heavy smokers were stoical and set a high pain report criterion during the postsmoking sessions—a result which is not congruent with their unchanged postsmoking $P(A)$ values. However, since the pain report criterion is readily influenced by attitudinal variables, this lack of agreement between these two independent measures is not surprising. The difference between the moderate and high consumers may be due to tolerance effects which clearly occurred in the latter group. The high-level smokers complained that they no longer got a "high"; in fact, several subjects accused the staff of substituting placebo cigarettes. The lack of a "high," and presumably the disappearance of perceptual enhancement, could explain the failure of this group to set a low pain report criterion. Indeed, during the postsmoking sessions they behaved stoically, a higher pain report criterion; for this group nothing was enhanced, not even pain.

During this study, $P(A)$ and B did not always move in a congruent fashion, that is, inversely. For the moderate smokers, increased discriminability $P(A)$ was associated with decreased criterion B, but this was not true of the heavy smokers. This result is not too surprising, since the criterion is a cognitive variable mediated by complex neocortical and limbic system activity, in contrast to thermal discriminability, the neurosensory component, which is mediated via spinal-thalamic tracts and sensory cortex. Pharmacologic effects, including tolerance, could occur at different doses in the sensory and cognitive compartments and affect $P(A)$ and B either in parallel or in opposite ways. Other investigators have reported that various physiological response systems may respond differently to marihuana and conclude that more than one pharmacodynamic mechanism must be involved.[17] Obviously, a single neural mechanism cannot explain our results. The presence of such complex mechanisms may account for much of the confusion in the literature. It is clear that detailed dose-response studies using sensory decision theory (SDT) procedures should be undertaken to determine whether marihuana (1) enhances pain, as was shown by the moderate smokers here and in the study by Hill et al.[12]; (2) decreases pain, as shown by the heavy smokers here and in other studies;[8,9] or (3) has no effect on pain as shown here by the lack of a statistically significant effect during the first two weeks of smoking and as concluded by Harris.[11]

Acknowledgments

This study was supported in part by grants from NIH GMNS (26461) and NIDA (5R010-A00894). The authors wish to thank R. R. Goetz, R. H. McCarthy, and B. Bemporad for their assistance with data collection.

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Appendix

Introduction to Nonparametric Sensory Decision Theory

The basic notions of SDT are introduced by means of a simple example; this is followed by a brief description of the nonparametric model.

Treatment of psychophysical, or stimulus-response, data by sensory decision theory (SDT) yields two measures of the subject's performance. The sensory measure, called $P(A)$ or d', employs error rate to estimate discriminability among stimuli of various intensities; it reflects neurosensory function and is uninfluenced by psychologic variables such as motivation, payoffs, and expectation. The report criterion B, or L_x, locates the subject's criterion for reporting pain, that is, his tendency to report or to deny the presence of a stimulus as a result of suggestion, motivation, or attitude.

The stimulus-response matrix of sensory decision theory appears in Table I-A. In the simple binary decision case, stimuli of two intensities are presented randomly, and the subject responds "high" or "low" or "painful" or "not painful." Dozens of stimuli are presented and judged. The report of "high" or "pain" to high-intensity stimulus is a hit; a report of "pain" or "high" to a low-intensity stimulus is a false alarm. A plot of hit rate against false alarm rate yields the

TABLE I-A

Stimulus-response Matrix for the Binary Decision Task

	Response	
	"Pain" or "high"	"No pain" or "low"
Higher-intensity stimulus	Hit	Miss
Lower-intensity stimulus	False alarm	Correct rejection

receiver-operating-characteristic curve of sensory decision theory. In pain research, typically more than two intensities of stimulation are presented, and the binary choice is extended to a rating scale of 8 to 12 categories. The analysis of the data, however, is essentially the same as for the binary task described in this example.

The two parameters of decision theory, discriminability and response bias, may be understood by viewing the response matrices of four subjects who differ in their ability to discriminate between high- and low-intensity stimuli and who differ in where they locate their subjective criterion for reporting pain (Table II-A).

Subject 1 (S-1) in the upper left-hand corner was presented 10 high- and 10 low-intensity stimuli in random order. When the high stimulus was presented, he reported "pain" or "high" nine times and "hot" or "low" once, a hit rate of 0.9. When the low-intensity stimulus was presented, S-1 reported "pain" or "high" four times, a false alarm rate of 0.4. Subject 1 is doing an excellent job of discriminating between the high- and low-intensity stimuli. This can be seen in the difference, 5, between the number of hits and the number of false alarms. This difference is closely related to the measure of discriminability $P(A)$; in this instance, $P(A) = 0.85$.

Subject 3, on the other hand, said "pain" to the high-intensity stimulus seven times and "pain" to the low-intensity stimulus six times. Obviously, this subject is doing a poor job of discriminating between the stimuli. He is almost as likely to report "pain"

TABLE II-A

Relationships Between Hit and False Affirmative Rates and Values of Discriminability $P(A)$ and Report Criterion B

		Low criterion, $B = 0.57$ Response			High criterion, $B = 1.23$ Response	
		S-1			S-2	
		"Pain"	"Hot"		"Pain"	"Hot"
	10 high-intensity stimuli	9	1	10 high-intensity stimuli	6	4
High Discriminability $P(A) = 0.85$		(5)			(5)	
	10 low-intensity stimuli	4	6	10 low-intensity stimuli	1	9
	Total	13	7	Total	7	13
		S-3			S-4	
		"Pain"	"Hot"		"Pain"	"Hot"
	10 high-intensity stimuli	7	3	10 high-intensity stimuli	4	6
Low discriminability $P(A) = 0.60$		(1)			(1)	
	10 low-intensity stimuli	6	4	10 low-intensity stimuli	3	7
	Total	13	7	Total	7	13

to the low-intensity stimulus as to the high-intensity stimulus. This poor performance is specified by the small difference, 1, between the number of hits and false alarms, $P(A) = 0.60$. A low $P(A)$ could be caused either by a small physical difference between the high- and low-intensity stimuli, or by a sensory defect, or by analgesia. It has been demonstrated that analgesics such as morphine[3] and nitrous oxide decrease discriminability. The discriminability measure reflects the functional state of the pain system without any dependence on the patient's subjective report of pain. It should be apparent that discriminability depends upon hit and false alarm rates alone and that whether the subject said "pain" or said "high" is irrelevant to this measure.

Subject 2 reported pain but six times; from the viewpoint of traditional psychophysics, he appears to be less sensitive to pain. However, the sensory decision theory matrix tells us that he possesses the same high ability to make discriminations as does Subject 1. For, although the hit rate, 6, and the false alarm rate, 1, are less, the difference between them is also 5, and discriminability remains the same, $P(A) = 0.85$. Subject 2 appears to be less sensitive because the hit rate is less, but he is not. Similarly, S-4 has the same poor discriminability as does S-3, $P(A) = 0.60$, but he reports pain less often.

The other sensory decision theory index of perceptual performance is the subject's report criterion B. The pain report criterion identifies the particular sensory experience along the sensory continuum above which the subject reports as "painful." The criterion locus reflects the subject's attitude toward pain or the meaning which he attaches to the word pain; it is influenced by nonsensory, that is, psychologic, or attitudinal variables. The total number of pain responses, that is, the sum of the hits and false alarms, indicates the subject's response bias or criterion locus. Subject 1 said "pain" nine times when the high-intensity stimulus was present and four times when the low-intensity stimulus was present. Thus, hits plus false alarms yield a total of 13 pain responses. This subject has set a low or lax response criterion, $B = 0.57$. The pain responses just pour out; he is willing to say "pain" even to relatively weak stimuli. Note that although S-1 and S-3 differ enormously in their ability to discriminate the stimuli, that is $P(A)$ differs, they both share a similar low criterion; for S-3, $B = 0.57$. Discriminability and criterion locus are independent of each other. This independence is fundamental to decision theory, and it is its most important contribution to psychophysical measurement. In contrast to S-1 and S-3, S-2 said "pain" only six times when the high-intensity stimulus was present and but once when the low-intensity stimulus was present, a total of seven times. Such a subject has set a high or strict criterion; he says, "pain" only when he is certain that the stimulus really hurts. Subjects 2 and 4 with high pain criteria are both stoics, $B = 1.23$. Clark[10] has demonstrated that a placebo described as a strong analgesic will cause subjects to raise their pain report criterion (fewer pain reports) while the discriminability measure remains unchanged.

Parametric sensory decision theory is based on a mathematical model which has been described in full in the instance of pain.[4] McNicol[18] has published an excellent introduction to the nonparametric model, a superior approach when the number of observations is small. A critique by Rollman[19] and a reply by Chapman[20] have also appeared.

The nonparametric sensory decision theory measure of discriminability $P(A)$ avoids the assumptions that the underlying noise and signal-plus-noise distributions are Gaussian and of equal variance. $P(A)$ is the area under the receiver-operating-characteristic (ROC) curve, a plot of hit rate against false alarm rates at each of the various criteria locations. When hit and false alarm rates are equal, the points fall along the negative diagonal; in this instance, the

area under the ROC curve is 0.5 and discriminability is zero. As discriminability increases, hit rates increase and false alarm rates decrease, causing points on the ROC curve to move toward the upper left and the area under the curve to approach 1.0. The advantage of $P(A)$ is that it indexes the degree of overlap of the signal-plus-noise and noise-alone distributions, regardless of their shapes, and that it incorporates all of the points on the ROC curve to yield a single measure of discriminability. Because it is based on more observations than d', $P(A)$ provides a much more stable measure of discriminability, particularly when the number of observations is relatively low.

McNicol has proposed a nonparametric measure of criterion locus, B, which, like $P(A)$, is based on all of the subjective responses. B is defined as the rating scale criterion at which the cumulated hit-plus-false-alarm probabilities equal unity. Equivalently, B locates that rating scale criterion at which half of the responses (to both stimulus intensities) are to higher response categories and half are to lower. An example from the response scale used in the present experiment will serve to introduce B. The subjects were asked to select their responses from the categories from "nothing" to "very painful" (see Table II in text). (The category numbers as well as the withdrawal times of less than 3.0 seconds were not given to the subject.) The response category with the shortest withdrawal time (below 1.99 second) is assigned the number 1, since it represents the most painful sensation, and the response category "nothing" is designated C (in the present study $C = 14$). Thus, high B scores represent a conservative or stoical pain report criterion, and low B scores represent a tendency to report "pain" frequently. For example, in the present study, $B = 13.5$ identifies a high pain report criterion, few pain reports, since half of the responses consisted of "nothing" and the remaining half are distributed among "maybe something," "faint warmth," etc. $B = 8.5$ means that half of the responses included pain responses ranging from very faint pain to very painful and withdrawal in less than 1.99 second, while $B = 2.5$ represents a very low pain report criterion, since half of the responses involved a report of "very painful" and a withdrawal from the stimulus in less than 1.99 second.