9

SIGNAL DETECTION THEORY PAIN MEASURES: EMPIRICAL VALIDATION STUDIES AND ADAPTATION-LEVEL EFFECTS

GARY B. ROLLMAN

Department of Psychology, The University of Western Ontario, London, Ont. N6A 5C2 (Canada)

SUMMARY

Proponents of the use of signal detection theory (SDT) in the assessment of pain modulation have generally looked for changes in d' to indicate a reduction of sensory function, and a change in criterion to indicate a modification of the subject's response bias or attitudinal predisposition. In the first experiment, both assumptions failed to receive empirical verification. Discrimination d' was equivalent before and after two strong levels of electrical current were reduced. The criterion parameter appeared to shift in a more conservative direction after the stimulus diminution. These results are used to question the validity of both detection and discrimination indices in the measurement of pain. An alternative means for describing the experimental results revealed a striking adaptation-level effect with implications for the assessment of both experimentally induced and endogenous pain. The outcome of a second experiment reinforced the adaptation-level theory interpretation of the results and provided additional evidence concerning the difficulties in evaluating SDT parameters in studies of potential analgesics.

INTRODUCTION

Some fundamental disagreements about the validity of signal detection theory (SDT) methods for the assessment of experimentally induced pain have surfaced in recent years. Rollman [33,34] and McBurney [27,28] have indicated that SDT is not suitable for the unequivocal separation of sensory and judgmental factors influenced by putative pain modulation procedures. The techniques utilized to obtain the SDT parameters (d' and criterion) measure the discrimination of stimulus pairs (or, in a special case, the discrimination of a stimulus and a blank). They do not measure pain. Consequently, one cannot be certain in the interpretation of experimental results. A reduction in d' need not indicate a reduction in experienced pain; a reduction in

experienced pain need not yield a reduction in d'.

Chapman [8] has acknowledged some of these difficulties while asserting that "discrimination and detection are the only windows presently available to the psychophysicist seeking to apply quantitative methods of inquiry to the mystery of pain." If that model fails to prove valid, it is not a cause for dispair. Other investigators have demonstrated the promise of alternative rigorous approaches in the scaling of human discomfort, based upon a variety of both direct and indirect psychophysical procedures [e.g., 21—23, 25,30,36].

The present study undertook an examination of some of the basic tenets of the SDT approach to pain assessment. To do so, it measured the discrimination of adjacent levels of electrically induced pain before and after an experimental manipulation selected to clearly reduce the sensory input of the stimuli. In this way, it provided a conceptual model of the techniques utilized previously to measure the effect of potential analgesics such as acupuncture [9,11,13,15,16,26], transcutaneous stimulation [6,13,15,29], nitrous oxide [11,12], diazepam [10], and cognitive manipulations [18,19]. Most proponents of the SDT approach to pain expect a reduction in d' if the sensory function is diminished by the modulation procedure [7,13,14] and an alteration in the criterion if the effect is to bias the verbal descriptions offered as a pain response [16]. Only one group of investigators [6,29] have concluded that such analyses are inadequate.

In this study, d' for a pair of stimuli was determined before and after a significant attenuation of the electrical current levels. The decline in sensory activity yielded no change in d' and a misleading shift in the response bias measure. Under one condition, the pain ratings failed to reflect the ordering of stimulus intensities. The resulting function demonstrated the existence of adaptation-level effects in the rating of experimental pain which have potential implications for assessing pain of internal origin.

METHODS

Experiment I

Three university students received trains of electrical pulses delivered through a pair of cream-filled silver electrodes attached to the volar surface of the left forearm. The electrodes were connected to the output of a constant-current stimulation system, programmed to provide 60 1-msec monophasic square wave pulses, with a frequency of 100 Hz. The onset of each train was signaled by a warning light presented 500 msec prior to the shock.

After several 1-h practice sessions, the subjects participated in 5 experimental sessions. At the start of each, an ascending method of limits was used to obtain estimates of the thresholds for pain and tolerance. Two "high" intensity (near the tolerance level) and two "low" intensity (closer to the pain threshold level) current values were selected. For ease of exposition, these intensities will be labeled I_1, I_2, I_3, and I_4. The latter two constitute the

high current pair. I_4 was determined by selecting the current level which was three-quarters of the way between pain threshold and tolerance threshold (0.75 (Tolerance-Pain Threshold) + Pain Threshold); I_3 was set at 0.94 I_4. Current levels I_1 and I_2 were determined by reducing I_3 and I_4, respectively, by 8%.

In each session, observers received 252 trials, blocked into two halves. One half consisted of 63 I_1 and 63 I_2 trials; the other half contained 63 presentations each of I_3 and I_4. During each half, the order of stimulus levels was random. As well, the selection of which of the two pairs, the low or the high, occurred in the first half of each session was randomly determined.

Subjects were instructed in the use of an 8-point rating scale to describe the experience resulting on each trial. A chart placed in front of them listed each category and the corresponding numeral: Nothing (1), Tactile Sensation (2), Very Faint Pain (3), Faint Pain (4), Mild Pain (5), Moderate Pain (6), Strong Pain (7), and Very Strong Pain (8). After each subjective rating was given, there was a 2-sec pause before the next presentation.

Experiment II

This experiment was similar to the first, with one important modification. In the previous experiment, I_1 and I_2 were presented randomly in one half of the session, and I_3 and I_4 were presented randomly in the other half. Experiment IIA constituted a replication of that study with 4 new observers. In experiment IIB, however, these same subjects received all 4 intensities in a random order throughout entire sessions of 252 trials. Five sessions per subject were run in both conditions A and B. Current values were selected by utilizing the rules for the first experiment. Subjects employed the same rating scale, but were permitted to add + and − responses if the sensation seemed to fall between the suggested categories.

RESULTS

Experiment I

The data were treated for individual subjects and sessions, utilizing the normal SDT approach [14]. For each stimulus, the proportion of ratings at each category was calculated. Cumulative proportions were then obtained, treating the highest rating category as one subjective criterion, the second highest as the next criterion, etc. In this way it was possible to determine how often the subject described each stimulus as a very strong pain, as a strong pain or very strong pain, as a moderate pain, strong pain, or very strong pain, etc. The probability of saying "very strong pain" given the more intense stimulus of a pair (the signal, s) is one determination in the SDT analysis. It can be labeled $P(8|s)$. The next value of interest is $P(7$ or $8|s)$ or $P(\geqslant 7|s)$. Such summations occur until one obtains $P(\geqslant 2|s)$. $P(\geqslant 1|s)$ is not utilized, since it must equal 1.0. Thus, the 8-point scale can give rise to 7 cumulative proportions. A similar analysis is performed for the weaker stimulus in the pair (sometimes called the noise, n). Corresponding cumula-

tive proportions for saying "Yes, it's painful" (Y) are plotted for the stronger and weaker stimuli of a pair, $P(Y|s)$ vs. $P(Y|n)$, yielding a receiver operating characteristic (ROC curve). The conceptual and mathematical procedures involved are described in further detail elsewhere [14,34].

The function presented in Fig. 1 illustrates both the nature of the ROC curve and the typical results obtained in this experiment. Examination of the circles, based upon the data obtained with the high pair (I_3 and I_4), reveals first that the ratings ranged from faint pain (4) to strong pain (7). Each of these categories was applied to both current values; however, I_4 was typically called moderate or strong, while I_3 was often described as faint or mild pain. Replotting the data on transformed, normal-deviate coordinates yields a straight-line function from which one can determine the sensitivity parameter, d'_e; in this case it equals 2.1.

The triangles represent the data from the other half of the session, discrimination of the low pair (I_1 and I_2). Although the intensities of these stimuli are reduced, the d'_e values are the same, since the data points fall along the identical ROC curve. The reduction in noxious input and the corresponding decrease in sensory activation did not alter the SDT parameter for the discrimination of adjacent pairs.

Fig. 2 presents the ROC curves for 5 sessions with each of 3 subjects. Again, the d' values for the low and high pairs are generally equivalent. Differences exist, however, in the values for the criteria. According to the usual interpretation, points close to the lower left-hand corner of the curve reflect instances where the events on stimulation trials exceeded an extremely conservative criterion; subjects had a maximal bias to report an absence of pain.
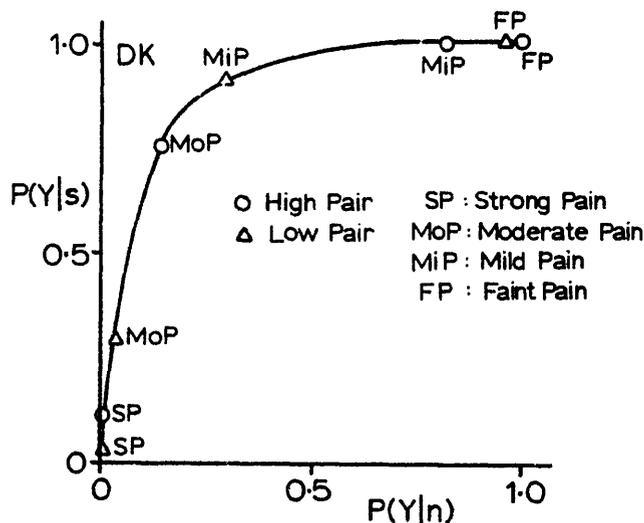

Fig. 1. Typical ROC curves for the discrimination of high intensity and low intensity stimulus pairs. The cumulative proportions of pain ratings (Y) greater than or equal to a specific category are plotted for the weaker (n) and stronger (s) signals in each pair. Data points for both pairs fall along the same function, although the response criteria for the low intensity pair appear almost consistently to the left of those for the stronger pain.
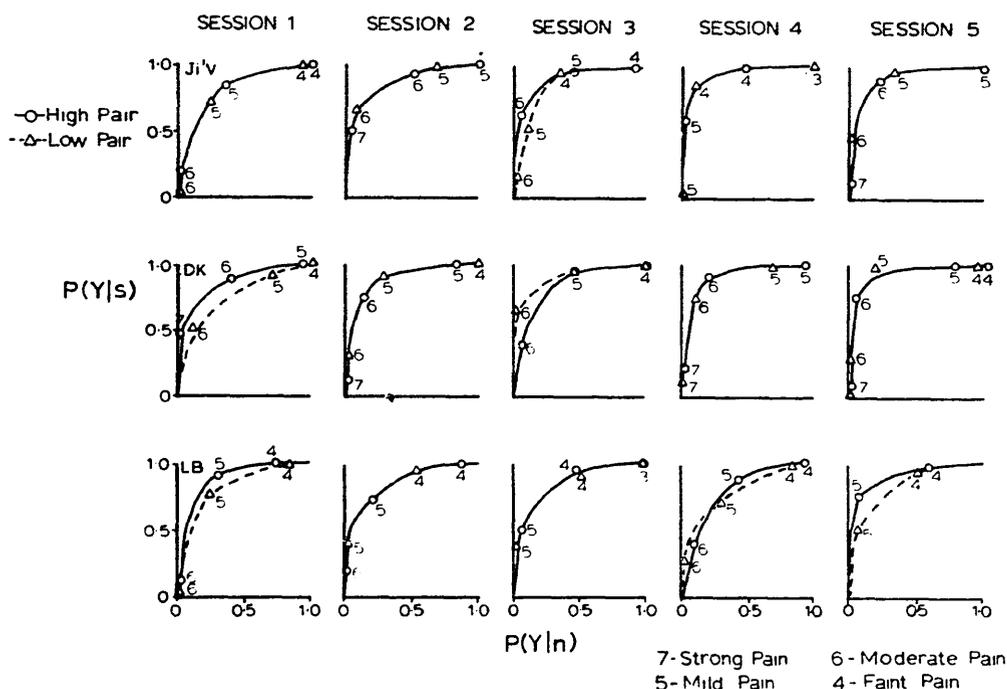
Fig. 2. ROC curves for each of 5 sessions for 3 subjects in experiment I.

Points closer to the upper right-hand corner represent the consequences of increasingly lower, more liberal criteria; the subjects had a maximal bias to report the presence of pain.

A variety of statistical conventions have been adopted by pain investigators to report the location of the criteria. The procedures are described elsewhere [e.g. 9,14]. Although the values for the criterion parameter differ, depending upon the method employed, the conclusions drawn from a comparison of results within a study are usually the same. For example, the mild pain criterion (a rating of 5) for the first ROC curve in Fig. 2 (Subject Ji'V, session 1) yields the following results for the low pair (triangle) and high pair (circle), respectively; criterion measure: L_x [14]: 1.10 and 0.66; C_x [14]: 0.71 and 0.39; per cent bias [9]: 12.5 and −43.2. By each of the 3 measures, the criterion is "higher" in the first instance.

This ordering of criterion values is highly consistent. In nearly all comparisons, the triangles corresponding to a specified rating category are closer to the lower left corner than are the circles. The general interpretation offered by the SDT investigators is that the criteria for the low intensity pair are higher than the criteria for the high intensity pair and because of these response biases, the subjects are less inclined to report the low intensity stimuli as painful.

Fig. 3 presents an alternative means for describing the data obtained in experiment I. For each session, it gives the proportion of trials at each intensity which the subject described as moderate pain or stronger ($\geqslant 6$), mild pain
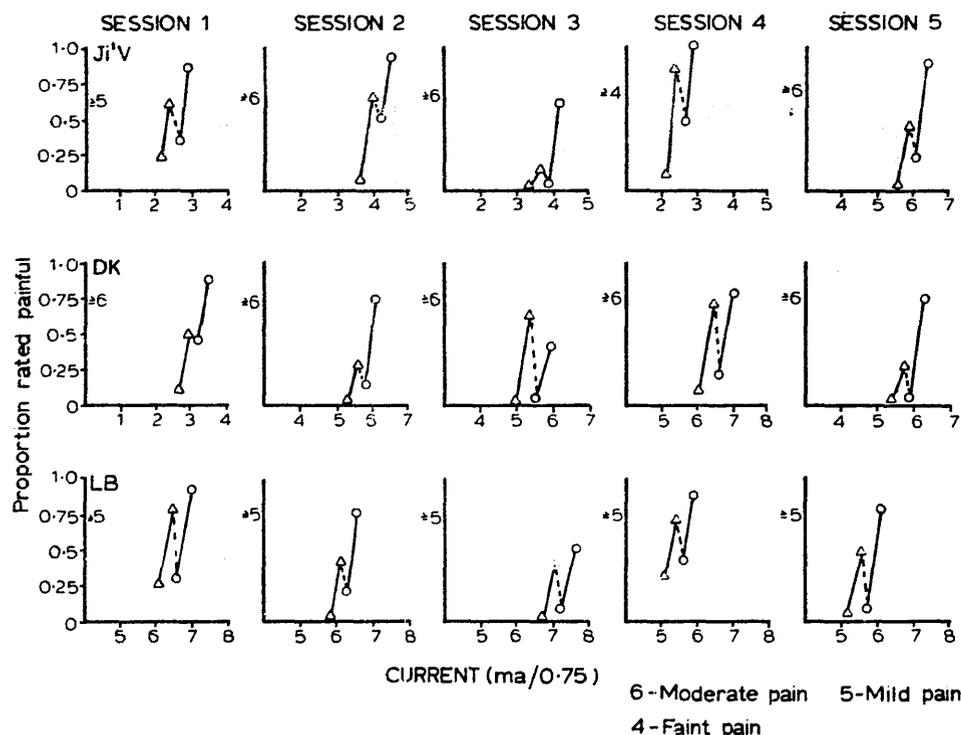
Fig. 3. The proportion of trials rated as painful (generally mild pain or greater ($\geqslant 5$) or moderate pain or greater ($\geqslant 6$)) for each of 4 stimulus levels in experiment I. The lower pair (triangles) were presented during one-half of each session; the higher intensity pair (circles) were presented during the other half.

or stronger ($\geqslant 5$), and, in one instance, faint pain or stronger ($\geqslant 4$). The category used to partition the results varied slightly between observers because of individual differences in how often subjects utilized the highest ratings. The functions represent an index of painfulness associated with each of the stimuli. The first two points, triangles, represent the responses given to I_1 and I_2; the latter two points, circles, represent the proportion of higher pain responses given to I_3 and I_4. Instead of the expected monotonically increasing psychometric functions, the points produced functions which show a marked "zig-zag" effect. Although I_3 was more intense than I_2, the proportion of pain ratings it obtained, under these experimental conditions, was less.

Experiment II

The zig-zag effect demonstrated in experiment I seemed to arise from the pairing conditions of that study. I_3 was consistently rated less painful than I_2. However, I_3 was always paired with the strongest intensity, I_4. Likewise, I_2 was always paired with the weakest level, I_1. A replication of experiment I was undertaken, with one critical addition: the 4 levels of shock were presented in a random order throughout each of 5 sessions (condition B). In the
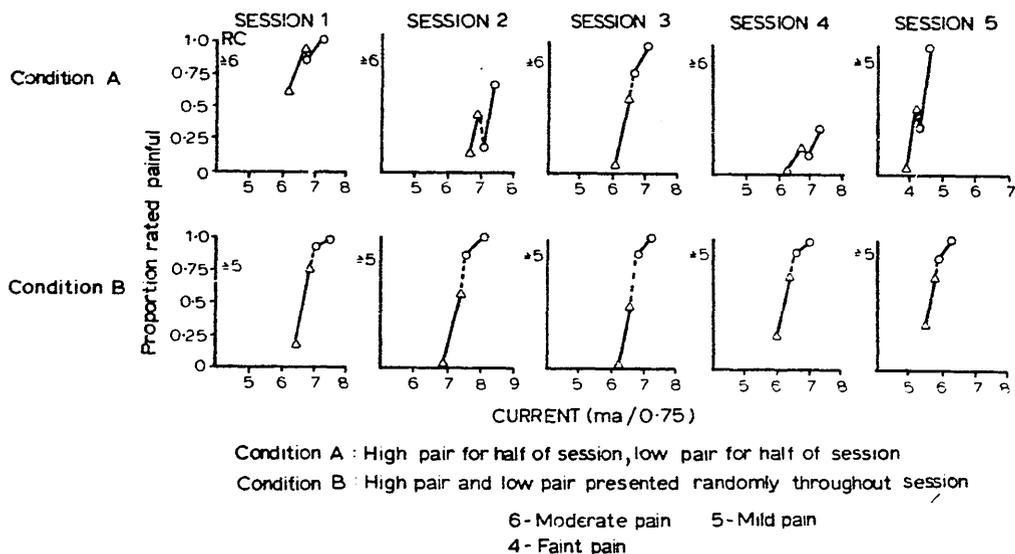
Fig. 4. The proportion of trials rated as painful for each of 4 stimulus levels in experiment II. In condition A, stimuli from each of the two pairs were repeated during half of the session. In condition B, the 4 intensities were presented repeatedly in random sequence throughout the entire session.

other 5 sessions, the low pair occurred in one half and the high pair in the other (condition A). Fig. 4 illustrates the dramatic difference produced by this manipulation. The functions at the top were obtained under the pairing conditions of experiment I. Four of the 5 functions present the zig-zag
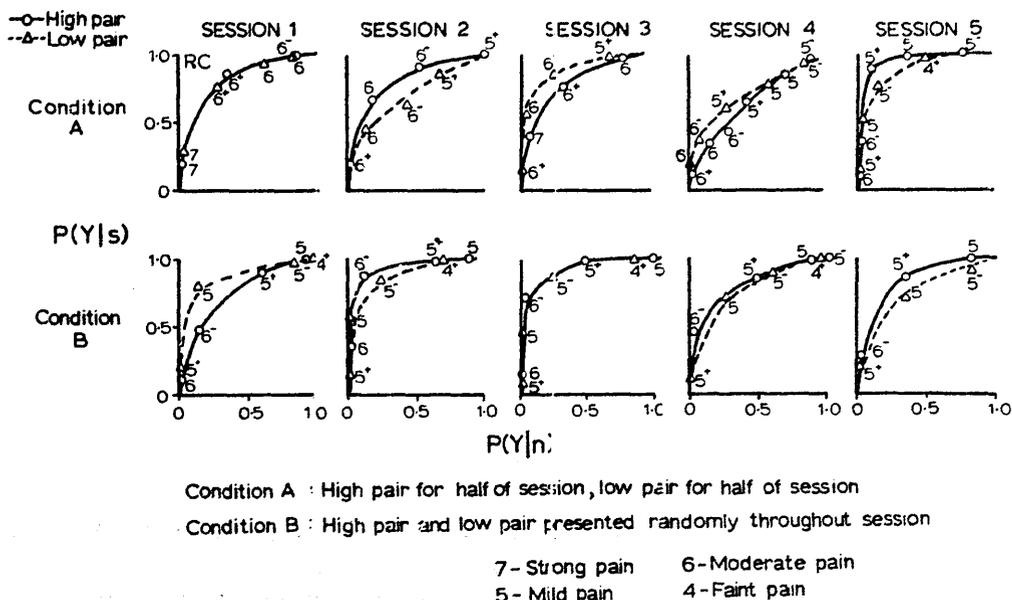

Fig. 5. ROC curves obtained in experiment II.

TABLE I

MEAN d'_e VALUES OBTAINED IN EXPERIMENT II FOR CONDITION A (low intensity and high intensity pairs presented in different halves of session) AND CONDITION B (all 4 intensities presented randomly)

Comparison	Mean d'_e for first variable	Mean d'_e for second variable	t (df)
Condition A, low pair vs. high pair	1.45	1.70	−0.972 (19)
Condition B, low pair vs. high pair	1.20	1.09	0.924 (19)
Condition A vs. condition B	1.57	1.14	2.453 (78) [a]

[a] $P < 0.01$.

effect. The functions at the bottom (condition B) were obtained during sessions of randomly mixed trials. All five functions are monotonically increasing; none show the zig-zag effect. The same held for the other 3 observers.

The nature of the pairing conditions strongly affected the functions relating pain reports to stimulus intensity, but they did not affect the general form of the ROC curves. Fig. 5 displays a set of typical curves obtained under each of the presentation formats. As in experiment I, the d' parameters were not significantly different when ROC curves were constructed for the discrimination of I_1 vs. I_2 and I_3 vs. I_4. Under both conditions A and B, the criterion parameters for the low intensity pair were higher ("a greater bias against calling them painful").

Although the d' values for the low intensity pair and high intensity pair did not differ in either condition, the results of the d' analysis presented in Table I reveal a critical effect. The mean d'_e in condition A (1.57), when subjects were rating only two stimuli within a block, was significantly higher than the d'_e in condition B (1.14), when 4 stimuli were presented in random order ($t(78) = 2.453, P < 0.01$).

DISCUSSION

This paper has described two experimental effects with ramifications for the measurement of pain: the consequences of intensity changes on SDT parameters and the zig-zag effect. Each will be discussed in turn.

The utility of SDT methods in pain research

Experiment I addressed itself to the following question: when the sensory component of noxious inputs is reduced by an experimental manipulation, need the alterations in parameters follow the expectations advanced by those who champion the SDT approach? Rollman [33,34] argued, on theoretical and logical grounds, that those expectations are in error.

Pain researchers took the signal detection model, which dealt with detection-discrimination in the basic senses, and extended it to the domain of pain

[34]. Chapman and Clark, among others, repeatedly used SDT parameters to assess the outcome of pain modulation studies. They assumed first that an analgesic which decreases the sensory component of pain would yield a reduction in d' (e.g., "a decrease in d' following the administration of an analgesic suggests that the drug has actually attenuated neural activity in the sensory system(s)" [14]; "it is evident (from the attenuated d') that sensory function was significantly reduced..." [7]; and "it is assumed that decreases in d' for a subject perceiving normally painful stimulation in a properly structured experiment are indicative of a loss of pain sensibility, and hence they reflect analgesia" [13]. They further assumed that changes in criterion are associated with modifications in the subject's "response bias" or "attitudinal predisposition" [13] (e.g., "(the criterion) reflects the perceiver's attitude, expectancy, or strategy"[13]; "increased bias against reporting a stimulus as painful is generally interpreted as a motivational-attitudinal change on the part of the experimental subject" [13]; and "it is evident that acupuncture's apparent analgesic effects (i.e., decreases in pain ratings) at higher levels of stimulation are due principally to response bias (i.e., criterion), whereas at the lowest level of stimulation, the effects were primarily sensory (i.e., d')" [13]).

Pain investigators, therefore, have typically associated a d' reduction with sensory modulation and a criterion reduction with change in attitude or response bias. The outcome of both of the present experiments failed to provide empirical support for these assumptions. The sensitivity measure, d', was determined for the discrimination of two intense signals before the sensory input was reduced by attenuating the noxious pulse trains. Afterwards, d' was again determined and was found to remain constant. The other parameter, the criterion, seemed to mistakenly suggest that the reduction in intensity resulted in a shift in response bias, since the criterion values moved to higher, more conservative levels.

Both findings are in accord with expectations advanced by Rollman [34]. He emphasized that an analgesic could modulate the sensory activity of experimental stimuli, reducing their neural impact. Although the pain they produce could be greatly diminished, the d' value, which measures only discriminative ability and not pain, would remain constant. Likewise, the criterion shift would be illusory. The criterion for reporting pain could remain unaffected with regard to some internal standard, yet the statistical measures used to describe criterion (L_x, C_x, or per cent bias) would move in a more conservative direction because of the shift in the underlying distributions.

Likewise, in experiment II, the change in intensities did not affect the d' values. The subjects, not surprisingly, reported the low pair to be less painful than the high pair. This arose because the stimuli were weaker and thus less painful, not because of an increased criterion. The usual interpretation of the SDT parameters would have yielded two erroneous conclusions: that the "modulation" had no effect on the physiological variables and that it increased the bias against calling the stimuli painful. In fact, the procedure reduced the physiological input and did not alter response bias through sug-

gestion or revised expectation. Since nearly all SDT studies of pain examined the discriminability of adjacent stimulus levels in order to evaluate the effects of modulation procedures [34], the validity of their interpretations remains questionable.

Chapman [8] suggested that studies of "detection" provide a means around this dilemma. Detection is a special case of discrimination; it examines the observer's ability to distinguish a very weak stimulus from a blank (internal noise). Rollman [34] reviewed (pp. 201—202) numerous methodological and theoretical shortcomings of this approach.

The d' for detection can be utilized in two ways. First, one can determine whether the discriminability of a weak stimulus and a blank is affected by a putative analgesic [e.g., 9]. However, it is not clear that such a demonstration is of any clinical importance, since an intervention which does successfully disrupt the detection of minute signals may be entirely without value in the attenuation of painful ones. Moreover, it is possible that the noise level itself can be attenuated by a modulation procedure, rendering the detection d' unsuitable. Despite Chapman's [8] contention that the SDT model "has no particular physiological reality" and that the modulation of noise has "not received the attention of SDT theorists or researchers", there is both a firm physiological basis [2,3,17,20,31,32] and a sizeable body of literature which proposes changes in spontaneous activity during processes such as dark adaptation [1,4,5,32,35].

Second, the d' value for the discrimination of a weak signal and a blank might form the basis for measuring the detectability of stronger values through an additivity procedure. Chapman [8] has suggested that this method provides a solution to some methodological difficulties, although it has not been used in experimental studies. A demonstration of additivity speaks for the internal consistency or *reliability* of the SDT ratings in one experiment, not the *validity*. The assumption that shifts in the underlying distributions will occur together is one possibility. It is also plausible that a modulation technique could interfere with only the weakest stimuli. Under some conditions, an additive procedure would suggest that d' for higher intensities had also been reduced.

Adaptation-level effects in the measurement of pain

The zig-zag effect was found in experiment I and was abolished by the procedures used in experiment II. In the first experiment, as noted previously, I_2 was paired with the weakest stimulus while I_3 was paired with the strongest. Although I_3 was more intense than I_2, the proportion of higher pain responses it elicited was lower. This phenomenon strongly resembles the adaptation-level effect reported by Helson [24]. In a wide variety of situations, particularly including psychophysical ratings, Helson discovered that judgments are not based upon the physical characteristics of one stimulus alone. Rather, they depend upon the actual stimulus, other stimuli in temporal or spatial contiguity to it, and a host of experiential factors. He developed a theory which emphasized that ratings are generally made relative to a changeable frame of reference.

The zig-zag effect can be understood within such a theoretical framework. The ratings of I_2 in experiment I (and condition A of experiment II) are higher than they are in experiment IIB because, in the former case, I_2 is being judged with comparison to either I_1 alone or a weighted average of I_1 and I_2. In the latter case, I_2 is being judged with comparison to a weighted average of I_1, I_2, I_3, and I_4. Adaptation-level theory predicts that the contrast of I_2 with a low anchor enhances subjective ratings. Likewise, I_3 is compared to a weighted average of I_3 and I_4 (or to I_4 alone) in experiment I, leading to lower ratings (a "negative enhancement") in comparison to experiment IIB. There, the weighted average used to establish the anchor would have been lower.

This phenomenon raises several implications for the measurement of pain. The first is its potential utility for assessing the magnitude of endogenous non-experimental pain. A patient with severe acute or chronic pain can be expected to have a different adaptation-level than a normal subject, since the internal discomfort itself serves as an anchor. Pain patients might not yield the zig-zag effect produced in experiment I, if both the low and the high intensity pairs are judged with reference to a strong internal comparison. Absence of the zig-zag effect might reflect the level of pain experienced by the patient; its restoration might serve as an index of the success of the treatment.

The second implication of the phenomenon is the additional warning it provides about the difficulties involved in SDT measures of pain. The ratings are not simple reflections of the peripheral activity induced by a stimulus or its consequent central effect. Ratings are affected by motivational factors. They are also influenced by the number and spacing of the stimuli chosen to obtain the measurements. In the SDT and pain literature, it is rare to have only two intensity levels within a session [34]; frequently as many as 6—10 have been employed. Rollman [34] cautioned, on the basis of psychoacoustic experiments, that performance may show a decrement as the size of the stimulus set is increased. The significant difference in d' values between conditions A and B of experiment II illustrates that this problem extends to the area of pain. It is necessary to appreciate, particularly when making comparisons across studies, that d' values are biased by contextual factors introduced in the research design and by violations of the assumption that experimental trials have independent effects.

ACKNOWLEDGEMENTS

REFERENCES

1 Barlow, H.B., Dark adaptation: a new hypothesis, Vision Res., 4 (1964) 47—58.
2 Barlow, H.B. and Levick, W.R., Three factors limiting the reliable detection of light

20

by retinal ganglion cells of the cat, J. Physiol. (Lond.), 200 (1969) 1—24.

3 Barlow, H.B., Levick, W.R. and Yoon, M., Responses to single quanta of light in retinal ganglion cells of the cat. In: T. Shipley and J.E. Dowling (Eds.), International Symposium on Visual Processes in Vertebrates, Vision Res., 11 (Suppl. 3) (1971) 87—101.

4 Barlow, H.B. and Sparrock, J.M.B., The role of afterimages in dark adaptation, Science, 144 (1964) 1309—1314.

5 Baumgardt, E., Threshold quantal problems. In: D. Jameson and L.M. Hurvich (Eds.), Handbook of Sensory Physiology, Vol. VII/4, Visual Psychophysics, Springer, Berlin, 1972, pp. 29—55.

6 Bloedel, J.R., McCreery, D.B. and Erickson, D.L., Analysis of the action of implanted stimulating devices using signal detection theory. In: J.J. Bonica and D. Albe-Fessard (Eds.), Advances in Pain Research and Therapy, Vol. 1, Raven Press, New York, 1976, pp. 433—437.

7 Chapman, C.R., An alternative to threshold assessment in the study of human pain. In: J.J. Bonica (Ed.), Advances in Neurology, Vol. 4, International Symposium on Pain, Raven Press, New York, 1974, pp. 115—121.

8 Chapman, C.R., Sensory decision theory methods in pain research: a reply to Rollman, Pain, 3 (1977) 295—305.

9 Chapman, C.R., Chen, A.C. and Bonica, J.J., Effects of intrasegmental electrical acupuncture on dental pain: evaluation by threshold estimation and sensory decision theory, Pain, 3 (1977) 213—227.

10 Chapman, C.R. and Feather, B.W., Effects of diazepam on human pain tolerance and sensitivity, Psychosom. Med., 35 (1973) 330—340.

11 Chapman, C.R., Gehrig, J.D. and Wilson, M.E., Acupuncture compared with 33 percent nitrous oxide for dental analgesia: a sensory decision theory evaluation, Anesthesiology, 42 (1975) 532—537.

12 Chapman, C.R., Murphy, J.M. and Butler, S.H., Analgesic strength of 33 percent nitrous oxide: a signal detection theory evaluation, Science, 179 (1973) 1246—1248.

13 Chapman, C.R., Wilson, M.E. and Gehrig, J.D., Comparative effects of acupuncture and transcutaneous stimulation on the perception of painful dental stimuli, Pain, 2 (1976) 265—283.

14 Clark, W.C., Pain sensitivity and the report of pain: an introduction to sensory decision theory, Anesthesiology, 40 (1974) 272—287.

15 Clark, W.C., Hall, W. and Yang, S., Changes in thermal discriminability and pain report criterion after acupunctural or transcutaneous electrical stimulation. In: J.J. Bonica and D. Albe-Fessard (Eds.), Advances in Pain Research and Therapy, Vol. 1, Raven Press, New York, 1976, pp. 769—773.

16 Clark, W.C. and Yang, J.C., Acupunctural analgesia? Evaluation by signal detection theory, Science, 184 (1974) 1096—1098.

17 Cohn, T.E., Theory of Signal Detectability: Application to the Analysis of the Recorded Activity of Single Cells of the Frog Visual System, Doctoral dissertation, University of Michigan, Ann Arbor, Mich., 1969.

18 Craig, K.D. and Coren, S., Signal detection analyses of social modelling influences on pain expressions, J. psychosom. Res., 19 (1975) 105—112.

19 Craig, K.D. and Ward, L.M., Social modelling influences on the discriminability of painful stimuli: a signal detection analysis, Unpublished manuscript, 1975.

20 FitzHugh, R., The statistical detection of threshold signals in the retina, J. gen. Physiol., 40 (1957) 925—948.

21 Goldberger, S.M. and Tursky, B., Modulation of shock-elicited pain by acupuncture and suggestion, Pain, 2 (1976) 417—429.

22 Gracely, R.H., McGrath, P. and Dubner, R., Ratio scales of sensory and affective verbal pain descriptors, Pain, 5 (1978) 5—18.

23 Gracely, R.H., McGrath, P. and Dubner, R., Validity and sensitivity of ratio scales of

sensory and affective verbal pain descriptors: manipulation of affect by diazepam, Pain, 5 (1978) 19—29.

24 Helson, H., Adaptation-level Theory, Harper and Row, New York, 1964.

25 Hilgard, E.R., Ruch, J.C., Lange, A.F., Lenox, J.R., Morgan, A.H. and Sachs, L.B., The psychophysics of cold pressor pain and its modification through hypnotic suggestion, Amer. J. Psychol., 87 (1974) 17—31.

26 Lloyd, M.A. and Wagner, M.K., Acupuncture analgesia and radiant-heat pain: a signal detection analysis, Anesthesiology, 44 (1976) 147—150.

27 McBurney, D.H., Acupuncture, pain and signal detection theory, Science, 189 (1975) 66.

28 McBurney, D.H., Signal detection theory and pain, Anesthesiology, 44 (1976) 356—358.

29 McCreery, D.B. and Bloedel, J.R., A critical examination of the use of signal detection theory in evaluating a putative analgesic — transcutaneous electrical nerve stimulation, Sensory Processes, 2 (1978) 38—57.

30 Melzack, R., The McGill Pain Questionnaire: major properties and scoring methods, Pain, 1 (1975) 277—299.

31 Nachmias, J., Signal detection theory and its application to problems in vision. In: D. Jameson and L.M. Hurvich (Eds.), Handbook of Sensory Physiology, Vol. VII/4, Visual Psychophysics, Springer, Berlin, 1972, pp. 56—77.

32 Rodieck, R.W., Maintained activity of cat retinal ganglion cells, J. Neurophysiol., 30 (1967) 1043—1071.

33 Rollman, G.B., Signal detection theory assessment of pain modulation: a critique. In: J.J. Bonica and D. Albe-Fessard (Eds.), Advances in Pain Research and Therapy, Vol. 1, Raven Press, New York, 1976, pp. 355—362.

34 Rollman, G.B., Signal detection theory measurement of pain: a review and critique, Pain, 3 (1977) 187—211.

35 Rushton, W.A.H., Bleached rhodopsin and visual adaption, J. Physiol. (Lond.), 181 (1965) 645—655.

36 Sternbach, R.A., Murphy, R.W., Timmermans, G., Greenhoot, J.H. and Akeson, W.H., Measuring the severity of clinical pain. In: J.J. Bonica (Ed.), Advances in Neurology, Vol. 4, International Symposium on Pain, Raven Press, New York, 1974, pp. 281—288.