Acupuncture, Pain, and Signal Detection Theory

Clark and Yang (*1*) have underscored an important aspect of the analgesic effects of acupuncture—that it tends to generate positive attitudinal shifts which lead the experimental subject to report pain less readily. However, their study may have provided an inadequate evaluation of the effects of acupuncture on sensory sensitivity to painful radiant heat stimulation, and three aspects of their report warrant consideration.

First, the available Chinese literature indicates that little or no analgesic effect should be evident in either of the experimental conditions employed by Clark and Yang. A test on acupuncture anesthesia states that 15 to 20 minutes of electrical acupuncture stimulation are required for the development of analgesia, and an induction period of this length precedes surgery (*2*). Furthermore, Peking investigators using potassium iontophoresis dolorimetry reported that cutaneous pain thresholds followed a negatively accelerated growth function as electrical acupuncture stimulation progressed, becoming stable only after about 50 minutes (*3*). Thresholds began to drop rapidly after needles were removed. Although threshold studies can be misleading, as Clark and Yang noted, the Chinese report does suggest that Clark and Yang did not allow sufficient time for an analgesic effect to develop. Their subjects were tested during an acupuncture stimulation period of 15 to 20 minutes and again after needles were removed.

Second, Clark and Yang picked a difficult area in which to demonstrate acupuncture analgesia. One of us (C.R.C.) was informed, while visiting Chinese operating theaters, that acupuncture analgesia is most often successful for surgery of the head and trunk, while effects are less reliable on the extremities. Kaada *et al.* (*4*) obtained the same information.

Third, sensory sensitivity (d') values in each treatment condition were calculated on the basis of only 12 stimuli at each of the two test intensities. The use of a small number of trials reduces the precision of signal detection indices as well as their reliability. While the mean values reported were remarkably consistent across anatomical test sites, the possibility exists that a difference might have been missed because so few trials were used.

We examined the analgesic effects of bilateral acupuncture at a single locus on the dorsal aspect of the hand in 42 volunteers, comparing its effects to those of nitrous oxide (*5*). High, medium, low, and zero intensity electrical stimuli were delivered to the central incisors in random order, with 75 trials at each level, and subjects gave rating scale responses to indicate the pain experienced with each stimulus in both baseline and test sessions. Electrical stimulation of the needles for acupuncture subjects began 20 minutes before testing and continued for the rest of the session. Analyzing the data by signal detection methods, we observed that controls improved in stimulus detection and discrimination over two sessions, while acupuncture subjects showed significant decreases in d' between baseline and test sessions, as did subjects given 33 percent nitrous oxide. In addition, significant changes in response bias, similar to those reported by Clark and Yang (*1*), were observed.

Acupuncture generates sensory analgesic effects for experimental dental pain, but sensory changes are of small magnitude and many trials are required to demonstrate them. Whether acupuncture affects cutaneous sensitivity to radiant heat stimulation has not been conclusively answered by the Clark and Yang report.

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Clark and Yang (*1*) report that acupuncture treatment did not alter the physical discriminability (d') of the two radiant heat stimuli presented, but did result in a reduced willingness of subjects to report pain (that is, a change in response bias to a stricter criterion) and hence "did not produce acupunctural analgesia." We feel that their conclusions regarding the effects of acupuncture are unjustified because of failure to meet the basic assumptions of the theory of signal detection (TSD).

Specifically, Clark and Yang fail to include an evaluation of subjects' responding in the presence of a clearly nonnoxious stimulus. As Swets (*2*) points out, "We imagine signal detection to be a choice between two Gaussian variables. One, having a mean equal to zero, is associated with noise alone; the other, having a mean equal to d', is associated with signal plus noise." Traditional applications of TSD allow objective measurement of both the nature and physical presence of signal (S) and noise (N) independent of subjects' reports. With pain, however, objective verification is not possible. Any stimulus that elicits reports of pain must be presumed painful, and its use would not, therefore, allow an estimation of the N distribution necessary to evaluate changes in pain sensitivity reflected by d'. To avoid the logical contradiction inherent in labeling as N a stimulus that elicits a pain response, one must devise a means of measuring responding in the objectively verifiable absence of noxious stimulation (for example, no stimulation at all). While Clark (*3*) makes the questionable contention that stimuli producing the perception of warmth may be employed for estimating the N distribution, data included in that same paper show a 370 mcal sec^{-1} cm^{-2} stimulus (the same stimulus treated as N in the acupuncture study) to be reported as painful 87 percent of the time. Thus, Clark and Yang, by comparing two radiant heat stimuli of different intensities without an appropriate N comparison, have violated the procedural requisites of TSD.

Although Clark and Yang interpret their failure to find a change in d' as an absence of analgesia, it seems just as likely to expect analgesia to result in a decrease in pain responses to all noxious stimuli, including those in their experiment associated with the lower stimulus intensity of 370 mcal sec^{-1} cm^{-2}. At a theoretical level, analgesia could result in the distributions of both noxious stimuli shifting about equally to the left along the decision axis. This hypothesis would predict that analgesia need not always be attended by changes in d' between stimuli. In the absence of an N evaluation, such shifts would be misconstrued as a change in response bias to a stricter criterion. Empirical support for this latter interpretation is found in a report by Chapman *et al.* (*4*), who demonstrated that 33 percent nitrous oxide did reduce d' for radiant heat stimuli when compared to a zero intensity condition but did not alter d' for adjacent nonzero stimulus pairs quite similar to those of Clark and Yang. Consequently, it could be argued that Clark and Yang's results are not inconsistent with the induction of "true" analgesia, and their omission of an appropriate N estimate led them to interpret distribution shifts as changes in response bias.

In conclusion, we maintain that published applications of TSD to analgesia research have produced, at best, equivocal results. Clark and Yang (*1*) and Chapman *et al.* (*4*), in the presence of similar data, have drawn opposite conclusions. Even explicit operational recognition of the assumptions of the model still poses serious questions about its applicability too detailed to be considered here. Without such operations, however, we feel results cannot be interpreted within the context of TSD.

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Clark and Yang (*1*) present an ingenious study of acupuncture analgesia but in trying to avoid certain problems in the definition of pain they have measured the wrong type of sensitivity. As they point out, the measurement of pain is complicated by the interplay of sensory and attitudinal variables. Signal detection theory allows one to separate these variables experimentally, provided one can present two stimuli that, by definition, differ with respect to some variable, such as the presence or absence of a light. The stimulus that contains the light is called the signal and the one that does not is called noise. This example would allow the measurement of the absolute sensitivity to the light. Instead of absolute sensitivity, one might be interested in the differential sensitivity, the ability to discriminate two intensities of light from one another. In that case, the more intense light would be the signal and the less intense, the noise.

As Clark and Yang realize, pain is problematic because it is not possible to present a stimulus that is either painful or is not perceived at all. If heat is used as the pain stimulus, an intensity too weak to evoke pain will produce the sensation of heat. So one cannot study the absolute sensitivity to pain, per se, using signal detection theory, because the independent variable is heat, not pain.

Clark and Yang try to get around the problem in the following way: two stimuli are presented that vary in intensity and the subject is instructed to use different labels to describe them. They analyze the differences in the way labels are attributed to the pair of stimuli. This is a legitimate procedure in signal detection theory but it yields a measure of differential sensitivity to various stimuli that are warm or painful (or both), not the absolute sensitivity to pain.

If the measurement of differential sensitivity to thermal stimuli is the best that can be done, why am I objecting? Two reasons. First, absolute sensitivity and differential sensitivity are not two aspects of a single sensory capability. It is not uncommon for differential sensitivity to increase and absolute sensitivity to decrease as a result of the same manipulation. Two well-known examples are sensory adaptation (*2*) and physical damage to a receptor (*3*). Adaptation is often thought of as simply a decrease in sensitivity of a system to some stimulus as a result of steady presentation of the stimulus. However, while absolute sensitivity has decreased, differential sensitivity has increased. Adaptation has been likened to a device that adjusts the range of maximum sensitivity of a sensory system to prevailing conditions. In sensory-neural deafness the threshold is elevated but the ear is more sensitive to variations in loudness, as revealed in the slope of the psychometric function at threshold and the rate of growth of loudness just above threshold. The fact that acupuncture produced no change in differential sensitivity to thermal stimuli does not imply that there might not have been a decrease in absolute sensitivity to pain.

Second, and more fundamental, because they must settle for measuring sensitivity to warmth or pain (or both) rather than pain per se, they confuse the ability to sense a stimulus with the quality of the sensation.

Since the requirements of signal detection theory have not been met, it is fruitless to discuss whether changes occurred in sensitivity (d') or criterion (L_x). Unfortunately, it does not seem possible to meet those requirements in principle.

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The above comments are welcome, especially since they serve to focus attention on the value of signal detection theory, which, unlike the traditional psychophysical methods, successfully distinguishes between the sensory and response bias components of the classical perceptual threshold (*1*). Pain is an extremely complex perceptual experience in which sensory and psychological factors are closely interlaced. Signal detection theory specifically addresses itself to such problems. The procedure may not be perfect, but it is certainly the best model presently available for the investigation of experimentally contrived pain. If nothing else, signal detection theory has made us aware that a decrease in pain report does not necessarily indicate an amelioration of the pain experience.

We cannot agree with the statement of Chapman *et al.* (*2*) that "the available Chinese literature indicates that little or no analgesic effect should be evident" under the conditions used in our study. With respect to duration of stimulation, our Chinese (Shanghai) manual *Acupuncture Anesthesia* (*3*) states that, for surgery of the forearm, "the acupuncture anesthesia induction time should be around 20 minutes." In our study (*4*), no analgesia was evident in any of our subjects even though the duration of acupunctural stimulation for all subjects except one ranged from 20 to 28 minutes (mean, 24.7) (one was stimulated for 46 minutes). The work of the Peking group (*5*) cited by Chapman gives the time course of pain threshold changes in various parts of the body following acupuncture at the Ho-Ku or Isu-San-Li sites (or both). The results of this excellent study do not contradict the instructions of our manual. The Peking group used one or two acupuncture sites and studied threshold changes in eight sites in the body, not including the forearm. In contrast, we used six acupuncture sites specifically prescribed for forearm surgery. Furthermore, their data on the leg (the only limb studied) indicates that two-thirds of the maximum (50-minute) analgesic effect was obtained in 25 minutes, the same duration as our stimulation period. Instead, we obtained absolutely no analgesic (lower d') effect.

In a recent symposium (*6*), durations of 8 to 30 minutes (*7*) were reported as being sufficient to produce fewer pain reports (so-called "analgesia"). Man and Baragar (*8*) reported an effect in 1 minute, and Chang (*9*) found that acupuncture took only a few seconds to stop the characteristic unit discharges found when the nucleus centralis lateralis of the thalamus is responding to noxious stimulation, in this instance a surgical wound.

With respect to the persistence of the analgesia following removal of the needles, our manual (*3*) states: "When the stimulation of the surgery is not too strong you can stop manipulating the needle or stop the electric current. . . . Whenever the stimulation of surgery becomes too strong, you must twist or stimulate the needle to keep the effect." Since the thermal experimental pain, from which the subject could withdraw if it became too painful, is innocuous relative to surgical pain, we believe that the analgesia could be expected to persist for some time. The Peking group (*5*) reported a decrease in analgesia almost immediately following the removal of the needles; however, even 10 minutes later about two-thirds of the analgesic effect remained in the limb. However, in the period after acupuncture we obtained neither a threshold effect (fewer pain reports) nor a decrease in d' or L_x. Again, there is very little agreement about duration of analgesia (*10*).

Chapman *et al.* (*2*) suggest that it is easier to demonstrate acupunctural analgesia in the head and trunk than in the extremities. Perhaps, but the manual (*3*) claimed that analgesia sufficient to permit surgery could be induced in the forearm. Furthermore, in figure 2 of the reference (*5*) cited by Chapman *et al.* (*2*), the degree of analgesia in the head is shown to be equal to that found in the ipsilateral leg, and even less than that found in the contralateral leg.

In sum, there is no compelling evidence that our failure to find analgesia was due to departure from accepted practice. Although it might prove effective to use longer stimulation times, as Chapman suggests, our conclusion is that the intensity of acupunctural stimulation should be the first candidate for future investigation. In our experiment (*4*) we increased the intensity of electrical stimulation until the subject refused to bear any more pain. Indeed, physical signs such as grimacing and clenching were occasionally present. However, success in China could be due to an ethnoculturally induced willingness to accept considerably higher intensities of acupunctural stimulation. Also, the use of preoperative analgesics and sedatives appears to be common in China (*11*), and would permit the administration of still higher intensities of acupunctural stimulation. Such intensities might induce a true analgesia (lower d') in addition to the raised pain report criterion (L_x) which we found. Perhaps the positive results reported by Chapman for dental pain were due to higher intensities of stimulation.

In the more readily specified realm of psychophysics, Chapman *et al.* (*2*) correctly note that when there are too few stimulus presentations the resulting estimates of d' and L_x may be highly variable, with the result that statistical tests may lack power to detect differences. We would prefer to use more than 12 stimuli per intensity; however, one runs into the problem either of tiring the subject or of omitting essential controls such as the simultaneous testing of a nonacupunctured area. In our study (*4*) (which included four other intensities in addition to the two mentioned in the report), each subject judged at least 432 stimuli in a period of about 2 hours. This approaches the edge of endurance of most observers. In any event, 12 presentations per intensity appear to be sufficient. First, as Chapman recognized, the mean values of d' were remarkably uniform at both sites and under all conditions. This uniformity makes it unlikely that differences existed which were not detected because tests lacked power. Second, it seems unlikely that the tests used could be powerful enough to detect differences in L_x but not powerful enough to detect differences in d'. Third, in earlier studies, Clark and co-workers have used as many as 25 stimuli (*12*) and as few as 12 (*13*) without encountering any marked change in variability. Finally, using fewer than 12 stimuli per intensity we found a dose-related decrease in d' following a median nerve block with dilute Carbocaine. If acupunctural analgesia had even begun to approach the effectiveness of a drug-induced peripheral nerve block, it would have been apparent in our data. We agree that the effect of the number of presentations on the standard error of d' and L_x deserves investigation. To this end we have presented the standard errors of the mean; we hope that other investigators will do likewise.

Hayes *et al.* (*14*) have drawn the attention of pain researchers to the importance of using nonnoxious stimuli including zero intensity. As they point out, if the d's are not ultimately anchored to zero intensity, it becomes possible for the distributions to shift to the left along the decision axis without a change in d' becoming apparent, and the effect of an analgesic might be missed. In fact, our present study (*4*), like our earlier ones (*12, 13*), did include stimulus intensities of 0, 120, 240, and 305 mcal sec^{-1} cm^{-2} as well as the two higher intensities of 370 and 420 mcal sec^{-1} cm^{-2}; data at the lower intensities were omitted from the *Science* report because of space restrictions. We found no significant effects for treatment (acupunctured versus control arm) or for period (before, during, or after acupuncture) for any of the other intensity pairs. Furthermore, in the critical test for the presence of analgesia, the treatment by period by intensity interaction, d' failed to approach significance ($F = 0.97$; d.f. = 8, 80; $P < .25$). Contrary to Chapman *et al.* (*15*), who found that nitrous oxide reduced d' at low heat intensities, we found no effect with acupuncture at any intensity.

Table 1. Various meanings of absolute and differential sensitivity; N, noise; S, intensity; the subscripts indicate the amount of activity in the sensory system; versus indicates the physical states being discriminated. N_1 is used rather than N_0 to indicate that spontaneous neural activity is present even in the absence of physical stimulation.

Background	Discrimination: Absolute sensitivity Blank = 0	Discrimination: Differential sensitivity Blank > 0
Absolute sensitivity Surround = 0	A N_1 versus $S_1 + N_1$	B $S_1 + N_1$ versus $S_2 + N_1$
Differential sensitivity Surround > 0	C N_2 versus $S_1 + N_2$	D $S_1 + N_2$ versus $S_2 + N_2$

Although the applicability of signal detection theory to pain has not been conclusively established, no other viable alternative exists. Studies of analgesia by traditional threshold methods yield far more equivocal results than do studies using signal detection theory. Threshold measures hopelessly confound sensory and attitudinal components, and lead to fruitless disputes about whether a procedure affects sensitivity to stimulation or the criterion for reporting pain. The need is for more research, not a return to outmoded psychophysical procedures.

McBurney (*16*) contends that the requirements for signal detection theory have not been met, and cannot be met in principle. Fortunately for researchers in pain, this conclusion is false. Since it is not clear which assumption has not been met, let us match those introduced by Green and Swets (*1*) to the present experiment. (i) Two or more quantifiable states of the world exist, in this instance, radiant intensities of 0, 120, 240, 305, 370, and 425 mcal sec^{-1} cm^{-2}. The independent variable is neither the sensory experience of heat nor that of pain, but the intensity of thermal radiation. (ii) The various physical states give rise to different distributions of observations. The observation may be regarded as unidimensional even when the sensory system has many dimensions, because it can be represented as a point in *m*-dimensional space; and there exists a likelihood ratio, or a unique set if the number of stimulus intensities is greater than two, for each such point. (iii) The observer responds with a decision or hypothesis about the physical state of the world. This decision arises from some strategy, that is, a decision rule, which partitions the set of possible observations into a number of response classes; in the present instance, "nothing" through "warm" and "hot" to "painful." (iv) In accepting or rejecting various hypotheses about the state of the world, the observer makes use of a posteriori probabilities. (v) The likelihood ratio is a single real number that expresses the strength of evidence associated with each observation. The dimensionality of the observation or event in no way influences the calculation of the likelihood ratio by the observer. It is assumed that observers can compare various sensory events with an ordinal scale that is monotonic with the likelihood ratio.

Green and Swets (*1*, p. 123) state: "It is important to note that the objectivity of detection theory methods does not require that the experimenter be able to score the subject as right or wrong; he need only know which value of the signal he presented on each trial. The experimenter cannot score the subject as right or wrong when he is measuring a transition from hot to cold, from not painful to pain, from beats to roughness, or from achromaticity to chromaticity. He can, however, determine the reliability with which an observer can discriminate between any two (or more) signals on one of these continua by determining an ROC curve . . ." Furthermore, it is not necessary to obtain pain reports; d's can be based on intensity reports (high or low) or on confidence ratings (*17*).

McBurney's other objection is that absolute sensitivity and differential sensitivity are not two aspects of a single sensory capability, since, for example, manipulation of sensory adaptation may cause the two types of sensitivity to move in opposite directions. This is certainly true. However, in the study of visual contrast thresholds as a function of stimulus duration, one would never attempt to plot a point from the absolute sensitivity function (scotopic threshold) in the midst of a relative sensitivity (photopic) curve. Confusion arises here because McBurney, and indeed many of the handbooks, use but two terms to describe the four situations portrayed in Table 1. Thus, it is not always clear whether absolute and differential sensitivity refer to the intensity of the stimulus background or to the intensity of the blank. (In signal detection theory "blank" refers to the zero or lower intensity stimulus.) In his second paragraph, McBurney's definition of absolute sensitivity is that of type A, and his differential sensitivity refers to type B and perhaps type D measurements. It is perfectly legitimate to compare type A measurements with type B, since both are absolute sensitivity with respect to background; similarly, types C and D measurements may be compared. It is improper, as McBurney points out, to compare type A, absolute surround sensitivity, with either type C or D. This we did not do. Since the thermal stimuli were applied to warm skin of a constant intensity (single adaptation level), we were only concerned with type C and D measurements, that is, with differential sensitivity with respect to background, and with both absolute (0 versus 120 mcal sec^{-1} cm^{-2}) and differential sensitivity (120 versus 240 to 425 mcal sec^{-1} cm^{-2}) with respect to discrimination. Clark (*18*) obtained 17 d' values at intervals of 25 mcal sec^{-1} cm^{-2} from 0 to 425 mcal sec^{-1} cm^{-2}. The "absolute sensitivity point" at 0 to 25 mcal sec^{-1} cm^{-2} was not unique and fitted the d' versus thermal intensity function. Defined in terms of discrimination, but not in terms of surround, absolute and differential sensitivity are, indeed, related aspects of a single sensory capability.

Let us recapitulate our argument. Values of d', independent of the quality of the subjective report ("warm," "pain," "high," or "yes"), measure the capacity of the nervous system to transmit information about the amounts of thermal radiation reaching the skin. Conceivably, transmission in fibers mediating pain could be blocked without affecting d'. This seems unlikely in principle, since d' depends upon total information transmitted, nor has it been found in practice. Recognized anesthetics (*15*) and analgesics decrease d', acupuncture did not; thus, we conclude that acupuncture is not an effective analgesic. For what it is worth, and forgetting signal detection theory entirely, both during and following acupuncture, our subjects felt that a skin incision would inflict the usual amount of pain.

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Hemispheric Asymmetry and Musical Performance

Bever and Chiarello (*1*) described an unexpected right ear superiority (putatively a left hemisphere dominance) for musicians in a melody recognition task. The usual observation (*2*) that recognition of melodic stimuli produces left ear superiority (right hemisphere dominance) was seen in a second group of listeners who were musically "naive." The counterindication was interpreted to be a result of musical training in which specialized left hemisphere analysis had been developed. The trained ("sophisticated") musicians apparently had learned to analyze the tonal sequence according to what Bever and Chiarello called "internal relationships of its components," an aspect of the serial or sequential (analytic) process of the left hemisphere (*3*). In contrast, musically naive listeners lacking specialized training had processed melodic passages according to the more holistic or unit mode of cognition in the right hemisphere (*4*).

To support the effect of musical training, Bever and Chiarello cited my report (*5*) of college musicians who also failed to show the usual left ear dominance for melodies. But my results did not demonstrate right ear superiority, whereas they did show left ear dominance for musical