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Signal Detectability and Medical Decision-Making

Signal detectability studies help radiologists evaluate equipment systems and performance of assistants.

Lee B. Lusted

Signal detection theory can be used to investigate two problems of interest to radiologists. First, the central concern in the study of radiographic image quality is to gain knowledge of the way in which physical image quality affects a diagnosis, not necessarily to design high fidelity imaging systems (*1*). Second, the increasing demand for diagnostic radiology examinations has stimulated studies to determine whether the effectiveness and efficiency of radiologists can be increased by the use of trained technical assistants.

Detection theory is a basis for treating discrimination experiments in psychophysics. In such experiments, one attempts to learn something about a sensory system by determining just how small a change in some aspect of the stimulus can be reliably detected. A central feature of this analysis is the distinction made between the criterion that the observer uses to decide whether a signal is present and his sensory capabilities as a signal detector. Receiver operating characteristic (ROC) curves can be used to separate the sensory and nonsensory variables. A large body of literature is available on signal detection theory in psychophysics (*2*) and the use of ROC curves (*3*).

The author is professor of radiology at the University of Chicago, Chicago, Illinois 60637.

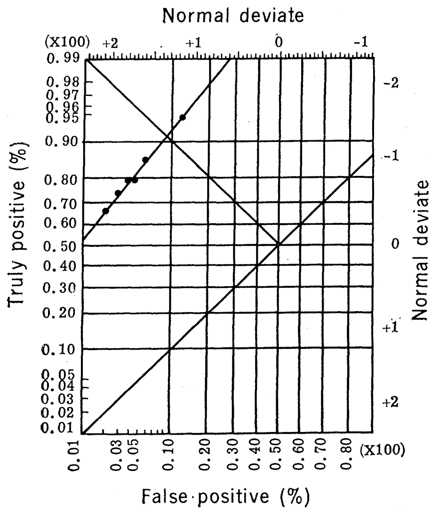
ROC Curve for Interpreting Chest Roentgenograms

In 1946 a group of radiologists and phthisiologists began an investigation to evaluate the effectiveness of various roentgenographic and photofluorographic techniques in detecting active pulmonary tuberculosis. Yerushalmy, who helped to initiate the study, has recently reviewed the results and the studies which followed (*4*). In the course of the investigation it was discovered that the variation in the interpretations of chest roentgenograms was of a disturbing magnitude: a physician would disagree with the diagnosis of a colleague on an average of one out of three times; on a second, independent reading of the same series of chest films, a physician would disagree with his own previous diagnosis on an average of one out of five times.

The results of the intensive studies of this phenomenon, which came to be known as observer error, are shown in an ROC graph in Fig. 1. The ROC curve is plotted on normal–normal coordinates (codex 41,453), according to the detection theory convention of false positive and true positive diagnoses on the *x*- and *y*-axes, respectively. Two parameters are abstracted from an ROC curve: the slope, and the sensitivity index d_e', where d_e' is defined as twice the normal deviates of the intersection of the ROC curve and the negative diagonal. The slope is interpreted as the ratio of the standard deviations of two distributions that, hypothetically, underlie the detection process. The measure d_e' is normalized by averaging the two variances of the underlying data-generating distributions. The more sensitively the observer performs as a signal detector, the larger the value of d_e'.

The ROC curve in Fig. 1 can explain the variation in roentgenogram interpretation. Suppose that the six points on the curve represent the diagnoses of six different physicians who have identical sensory capabilities for detecting the signals (film densities) of tuberculosis on the chest roentgenogram, but they have different criteria for what densities should actually be called tuberculosis. One assumes that they have the same sensory capabilities because the index of detectability, d_e', is the same for each physician.

The upper points on the curve represent individuals with more liberal decision criteria, whereas the lower



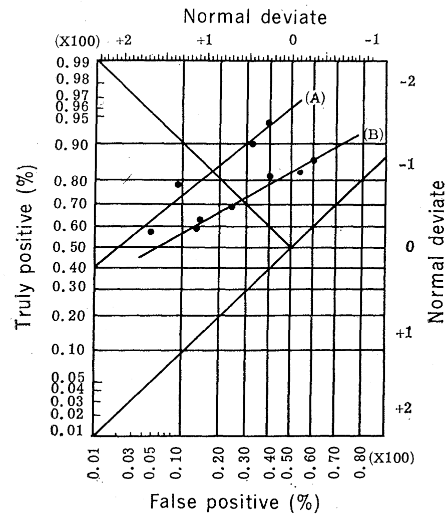


Fig. 1 (left). Receiver operating characteristic (ROC) curve for the interpretation of chest photofluorograms for pulmonary tuberculosis. Fig. 2 (right). ROC curves for the interpretation of mammograms. Curve A represents interpretation by radiologists. Curve B represents interpretation by paramedical personnel.

points represent individuals with more stringent criteria. Garland (*5*) attempted to assess the effect of a film reader's attitude by asking radiologists to read a group of chest films twice, first with a liberal or lax attitude and then with a conservative or strict attitude. The liberal attitude would reflect a policy of "When in doubt, call the shadow positive." This policy increased the number of true positive lesions detected, but it concomitantly increased the percentage of false positives. Garland showed that it is possible for a radiologist, by conscious effort, to change his operating point on an ROC curve. Likewise, it is difficult for a physician to maintain a constant decision attitude and error rate. Movement of a physician's operating point on the ROC curve is reflected in the interobserver variation of about 30 percent and the intraobserver variation of about 20 percent. We are interested here in studying the differences in observers' sensory capabilities rather than the differences in their criteria for decisions.

Evaluating the Usefulness of Radiologic Equipment Systems

Radiographic image quality has been studied in terms of line spread function and modulation transfer function (*6*), but the image that reproduces the primary input most faithfully from a physical standpoint may not contain the most useful diagnostic information (*1, 7*). The problem is to describe imaging systems in terms of decision-maker performance and, in doing so, to relate physical measurements such as modulation transfer function to the decision maker. Signal detection theory and ROC curves provide a means for studying this problem.

Kundel, Revesz, and Stauffer (*8*) have investigated the effect on observer performance of using a television chain to transmit a radiographic image. Radiologists were asked to view chest radiographs, some of which contained a simulated nodule in the lung. The series of films was viewed directly on a viewbox and reread later from a television monitor. The results are shown in Table 1. Since the value of d_e' is smaller for the radiologist's performance with television viewing, it is possible that the television chain in this experiment degraded his performance as a detector of lung nodules. This example illustrates a method which may be applied to the design and evaluation of imaging systems.

Table 1. A comparison of the error rates of observers for detecting nodules by different modes of viewing the films (*8*).

Viewing mode	Observers (No.)	False diagnoses (%) Negative	False diagnoses (%) Positive	d_e'
Direct viewing	21	14	24	1.91
Unprocessed television	3	34	30	0.98
Television with contrast enhancement	10	24	26	1.46

Evaluating the Performance of Radiologists' Assistants

The discrepancy between the number of radiologic procedures performed and the number of radiologists available to do the examinations has resulted in criticism by some observers (*9*). Several radiologists are investigating the feasibility of training paramedical personnel (x-ray technologists, secretaries, and so on) to screen radiographs (*10–12*). Paramedical personnel work under the supervision of the radiologist, but they increase his effectiveness by decreasing the number of radiographs he must interpret. Evaluation of performance is important. The radiologist must decide when the technologist is prepared to accept the responsibility for screening radiographs.

Alcorn and O'Donnell (*10*) have trained paramedical personnel to screen radiographs of the breast (mammograms) for cancer. The personnel were two medical secretaries, two x-ray technologists experienced in mammography, and two senior x-ray technologists not experienced in mammography. The object of the screening process is to have the paramedical personnel study the mammograms taken each day in the hospital radiology department and to separate the films into two groups: namely, a group that is positive or suspected to be positive for cancer of the breast, and a group that is negative for cancer.

For testing and training, Alcorn and O'Donnell used mammograms of cases that had been proved malignant or nonmalignant on the basis of a pathologist's report. The performance of radiologists in detecting malignancy is shown as ROC curve A, Fig. 2 (*13*). The performance of the six paramedical personnel is shown in curve B, Fig. 2

Table 2. Interpretation by technologists (Tech), senior residents (Res), and staff radiologists (Staff) of 100 chest roentgenograms—52 positive, 48 negative (*12*).

Observer	d_e' Pretraining	d_e' After 5 months' training	d_e' End point of experience
Tech 1	1.12	2.08	2.53*
Tech 2	0.08	1.42	2.63*
Res (5)			2.74†
Staff (3)			3.02‡

* Technologist after 5 months of additional experience. †Five senior residents, each with an M.D. and 4 years of training in radiology. ‡ Three staff radiologists, each with an M.D. and more than 4 years of training in radiology.

(*10*). The secretaries and technologists are not as sensitive in detecting breast malignancy as the radiologists are, but further training may improve their performance.

About 40 percent of the roentgenograms in an average hospital radiology practice are chest examinations. Sheft *et al.* (*12*) have reported their experience in training x-ray technologists to screen chest roentgenograms. They selected 100 chest roentgenograms (52 known positive, 48 negative) as a test series. The performance of the technologists before training and after training is compared with that of senior radiology residents and staff radiologists. For this screening, the technologists were asked to indicate all chest films which showed any type of abnormality. The results are shown in Table 2. The index of detector sensitivity, d_e', shows that the technologists improved in ability to detect chest film abnormalities with training and experience. At the end of 5 months' experience, their screening performance did not differ significantly from that of the senior residents and staff radiologists.

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NEWS AND COMMENT

Higher Education: Will Federal Aid Favor Students or Institutions?

Representatives of the nation's colleges and universities have been making their annual trek to Capitol Hill to testify at hearings on higher education. In recent years these seminars have proved metaphorically academic since neither major legislation nor new money resulted. This year, however, practiced observers think things may be different.

What appears to be developing is a contest between the Nixon Administration and Hill Democrats, who control Congress, to determine the direction federal aid to higher education will take in the 1970's. The big question, which emerged early, is whether primary federal emphasis will be placed on aid to students or aid to institutions.

In his message on higher education on 22 February, President Nixon elaborated on the program he had already laid out in financial terms in his budget. The President advocates a legislative package designed to increase opportunities for higher education for students from low income families and to encourage research, reform, and innovation in institutions of higher education through creation of a National Foundation for Education financed at a rate of $100 million for the first year.

The Nixon plans were met with immediate criticism and with counterproposals from Democrats on both sides of Capitol Hill. House Democrats were quick to express misgivings about the potential effects of the Nixon proposals on students from middle income families and on private colleges and universities. Several Democrats have introduced alternatives which differ in detail but in most cases provide some form of general-purpose institutional aid.

Spokesmen for the higher education lobby have avoided direct attacks on the Administration program but have made it clear that it doesn't meet their needs. Inflation and increasing enrollments are putting painful pressures on colleges and universities, and the argument is being made that if federal action took the form of major increases in student aid the institutions would have no recourse but to push tuition higher and higher.

It is something of an exaggeration to say that the Administration has rejected institutional aid. As Department of Health, Education, and Welfare Secretary Elliot L. Richardson phrased it at House hearings, the Administration was not satisfied with proposals made so far for institutional aid. HEW officials have indicated that one of the tasks of the proposed National Foundation for Higher Education would be to look at the options on institutional aid. And Representative Albert H. Quie (R–Minn.), ranking Republican on the House Labor and Education Committee, introduced the Administration's higher education bills but also introduced a measure of his own which would provide grants to colleges and universities based on the number of degrees awarded. It is fair to say, however, that in view of the Administration's concern about controlling the impending budget deficit, any substantial general-aid measure this year would hardly fit in with White House plans.

In many ways the Administration and its congressional opponents are refighting last year's battle from the same trenches, a battle that ended in an impasse. This year, however, there are some significant changes in circumstances. Through a legislative quirk, virtually all major education legislation expires in June. Financially, some colleges and universities are sinking, and the SOS's are getting through to their senators and congressmen. On the Washington scene, the higher education lobby continues to rise above its own heterogeneity and maintain cohesion. And all of this increases the likelihood of action.

At issue this year is the portion of federal aid legislation administered by HEW's Office of Education (OE). This legislation carries a major share of fellowship and student-aid money, construction funds, and financing for special-purpose "categorical" programs but can be compared with the visible tip of the iceberg. Federal funds actually expended in the higher education area amount to a total of nearly $6 billion a year, but the bulk of the money goes into student aid and support of research. And most of the