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Finding lung nodules with and without comparative visual scanning

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Detection of lung nodules contained in chest X-ray films was studied during both tachistoscopic presentation and free search. Lung nodules were first rated for their visibility against the anatomical background of the chest films. With tachistoscopic presentation, detection accuracy was influenced by rated visibility and by exposure durations up to 180 msec. Eye movements and fixations were recorded during free search. These measures indicated that radiologists use a comparative scanning strategy to differentiate nodules from anatomical structures. The frequency of comparative scans was influenced by rated visibility: Less visible nodules received more comparisons than the more visible nodules. We believe that the radiologist compares suspected nodules with the features of normal structures which serve as references for decisions.

Radiological examinations are frequently performed to assist clinicians when making decisions about the health and subsequent care of patients. Decision-making is based upon the patient's clinical history, the reason for the radiological examination, and the interpretation of features on the radiograph. Up to 30% of the small abnormalities, such as lung nodules, on chest radiographs are not reported, although they can be seen when pointed out later (Guiss & Kuenstler, 1960; Smith, 1967). These errors of omission can have serious consequences, since a frequent indicator of lung cancer is small nodules. Such errors have been attributed to either a failure to look at the abnormality or a failure to recognize the abnormality when viewed (Carmody, Nodine, & Kundel, 1980a; Kundel, Nodine, & Carmody, 1978).

Decision-Making and Visual Search

Studies of the eye movements and fixations of radiologists showed that large portions of the lung fields on chest films are not examined with foveal vision even though the radiologists report an adequate scan (Kundel & LaFollette, 1972; Kundel et al., 1978; Llewellyn-Thomas & Lansdowne, 1963). Rather, radiologists tend to sample areas of films for evidence of abnormalities, basing the search strategy on the reason for the examination (Kundel, 1974; Kundel & LaFollette, 1972; Kundel & Wright, 1969), as well as on their clinical experience and features of the film that attract visual attention (Kundel & Nodine, 1975, 1978; Kundel et al., 1978). These selective aspects of visual search are not unique to radiology and have been reported for tasks such as picture descriptions (Antes, 1974; Mackworth & Morandi, 1967; Nodine, Carmody, & Kundel, 1978; Yarbus, 1967), interpretation of aerial photographs (Enoch, 1960), and target search in line drawings (Nodine, Carmody, & Herman, 1979; Nodine et al., 1978).

Nodules located in unscanned areas of the lungs are generally not reported (Kundel et al., 1978). Analyses of the visual scanning patterns of radiologists searching chest films for nodules showed that 30% of the misses were search errors in which the nodule was not fixated within a 3-deg useful field of view. In the remaining 70% of misses, nodules were fixated but the radiologist failed to report their presence.

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Search errors are a general phenomenon: Viewers fail to fixate and fail to report targets during visual search for words hidden in line drawings (Nodine et al., 1978, 1979), and photointerpreters tend to concentrate fixations near the center rather than near the edges of aerial photographs (Enoch, 1960). Attempts to improve the scanning coverage of viewers by limiting the display size resulted in higher detection rates of geometrical targets (Ellis, 1968; Townsend & Fry, 1960), and Llewellyn-Thomas (1969) suggested that partitioning a chest film should increase the scanning coverage by the radiologist and therefore reduce search errors.

Segmented Search and Comparative Scanning

Chest films were inspected by radiologists for lung nodules under two viewing conditions—segmented search, in which films were divided into six sections and viewed piecemeal, and global search, in which the complete film was viewed in its entirety (Carmody, 1980; Carmody, Nodine, & Kundel, 1980b). Segmented search was expected to reduce search errors by assuring fuller visual coverage of the films. Viewing conditions did not differ in the number of nodules found and reported, although segmented search led to 37% more false positives. Thus, overall decision performance, as assessed by an index of detectability (Green & Swets, 1974), is lower in segmented search.

Poorer decision-making performance during segmented search is presumably due to the radiologist's being prevented from viewing ambiguous film features in the context of the entire chest. One radiologist tended to view two segments alternately prior to making decisions about ambiguous film areas, and this radiologist had similar false-positive rates in both viewing conditions. It was hypothesized that radiologists use comparative scanning strategies to make visual comparisons of suspected nodules with other film features in order to differentiate distinctive aspects that might denote a nodule (Carmody, 1980; Carmody et al., 1980b). Observers in these studies reported that some of the nodules were more visible relative to the anatomical surround; that is, nodule "signals" varied in their confusability with the "noise" of the background features (Estes, 1972). It was also hypothesized that comparative scanning would occur more frequently with increased confusability between nodules and background features.

The experiments reported here were designed to examine the comparative scanning hypothesis. Using both tachistoscopic and free-search presentations, we attempted to determine (1) whether comparative scans were necessary for nodule detection and (2) whether the frequency of such scans was related to the visibility of the nodule against the anatomical background of the chest. Experiment 1 describes the rating of nodule visibility; nodules varied in their visibility in the context of the chest film. Experiment 2 examined detection accuracy when nodules were viewed directly under tachistoscopic presentations which varied in duration and prevented comparative scans. This experiment was previously reported as an examination of fixation durations (Carmody et al., 1980a); detection rates were examined as a function of rated visibility and presentation duration, and a brief description of the method is presented here. Visibility ratings influenced detection accuracy during direct viewing. In Experiment 3, eye movements and fixations were recorded as radiologists searched the same chest films, and the records were examined for evidence of comparative scans. Such scans were found to precede decision-making, and their frequency increased as nodules decreased in visibility.

EXPERIMENT 1: RATINGS OF NODULE VISIBILITY

Method

Subjects. Four male radiologists from the Temple University Department of Radiology served as volunteer subjects.

Stimuli. A set of 26 films were copied from two original normal chest films, one of a man and one of a woman. Thirteen masks were made by exposing sheets of 35 × 43 cm film to a controlled light (Kundel, Revesz, & Toto, 1979). One mask was uniformly gray; the other 12 masks were exposed to the same light, but the shadow of a round, opaque disk, placed near the film, created a sharply edged nodule, 1.3 cm in diameter, of contrast .14 against the gray surround. Both of the original chest films were superimposed on each of the 13 masks and copied photographically onto 35 × 43 cm film. This procedure resulted in 24 abnormal films, each having a single nodule located in different areas of the lungs, and two normal films which matched the overall density of the abnormal films. For this experiment, the 24 abnormal films were arranged randomly for each subject and displayed simultaneously on 24 viewboxes. The normal films were reserved for Experiment 2.

Procedure. Individual subjects sorted the 24 films into five categories based on the visibility of the nodule. Categories did not require an equal number of films, and inspection time was unlimited.

Results

Fifteen nodules received the same judged ratings from all subjects. Six nodules elicited the same ratings from three of four subjects and were assigned the modal ratings. The remaining three nodules were assigned the mean rating. Nodules were distributed by visibility as: low visibility, 5 nodules; low-medium, 4; medium, 5; medium-high, 6; and high visibility, 4.

EXPERIMENT 2: NODULE DETECTION UNDER DIRECTED VIEWING

Method

Subjects. Three male volunteers, two experienced film readers and one radiologist, from the Temple University Department of Radiology served as subjects. All had normal or corrected-to-normal vision, and none had served in Experiment 1.

Stimuli. Twelve copies of each normal chest film and one copy of each of the 24 abnormal films from Experiment 1 were made into 35-mm slides which were projected to the size of the films. A set of 48 preexposure crosses were copied onto 35-mm slides; two crosses coincided with the nodule location, when projected, for each of the 24 abnormal images and the equivalent anatomical location in the 24 normal images. With subjects seated 63 cm from the screen, the projected nodules subtended 1.3 deg and the crosses subtended 1.0 deg.

Apparatus. Stimuli were presented tachistoscopically by three slide projectors with shutters under control of a digital timing circuit, and trials were started by subjects. The three projectors presented a preexposure cross, a chest image, and a patterned mask, respectively. The subjects entered responses via a five-position switch to a permanent file stored on a disk of a PDP-11/40 computer (Digital Equipment Corporation).

Procedure. On one trial, the subject fixated the preexposure cross and then initiated a chest image by a keypress; the duration of the chest image was 60-480 msec, and it was followed by a mask for 5 sec. The subjects decided if the cross defined the location of a nodule and assigned a confidence rating (1, high confidence of nodule presence; 2, low confidence of nodule presence; 3, no decision; 4, low confidence of normal image; 5, high confidence of normal image).

Stimuli were presented for eight exposure durations: 60, 120, 180, 240, 300, 360, 420, and 480 msec. The subjects viewed a random arrangement of all stimuli in a session, blocked by exposure durations; there were 48 randomly arranged sessions, 6 at each duration, for a total of 6,912 presentations. The subjects were aware that half of the presentations were of abnormal films and half of normal films.

Results

Correct decisions about normal and nodule film area were examined by a 2 (film area: normal or nodule) by 8 (exposure duration) analysis of variance with repeated measures on both factors. Normal areas were correctly identified more often than nodules [$F(1,24)=4.39$, $p<.05$]. Exposure duration was a significant factor [$F(7,168)=300.00$, $p<.001$], and the Film Area by Exposure Duration interaction was significant [$F(7,168)=4.53$, $p<.05$]. Planned comparisons (Kirk, 1968) found that both normal and nodule film areas were more correctly identified with increased durations, from 60 to 180 msec; after 180 msec, nodule identification did not improve beyond 84% [$t(34)=.23$, n.s.]. Identification of normal film areas increased with longer durations until 360 msec, after which performance reached a plateau at 95% [$t(34)=1.57$, n.s.].

To explore the effect of rated visibility on detection accuracy, a 5 (visibility rating) by 8 (exposure duration) analysis of variance with repeated measures on both factors was performed. Significance was found for the factors of visibility rating [$F(4,16)=23.66$, $p<.001$] and exposure duration [$F(7,28)=129.52$, $p<.001$], and for their interaction [$F(28,112)=2.29$, $p<.001$]. From the results of post hoc analyses (Kirk, 1968) of detection accuracy at 480 msec, the five levels of visibility rating were combined into three categories on the basis of differences between rating means: The high (100% accuracy) and medium-high (100%) visibility ratings were combined into a high category; the medium (84.4%) and medium-low (83.3%) visibility ratings were combined into a medium category; the low (53.3%) visibility rating defined the low category. These categories were significantly different: high > medium [$t(34)=3.64$, $p<.01$]; medium > low [$t(34)=4.12$, $p<.01$]. Figure 1 illustrates these combined categories as functions of exposure duration. For all levels of visibility rating, detection improved with longer exposure durations from 60 to 180 msec, after which detection did not improve [$t(34)$ values range from 1.74 to 10.37, $p<.05$ in all cases).

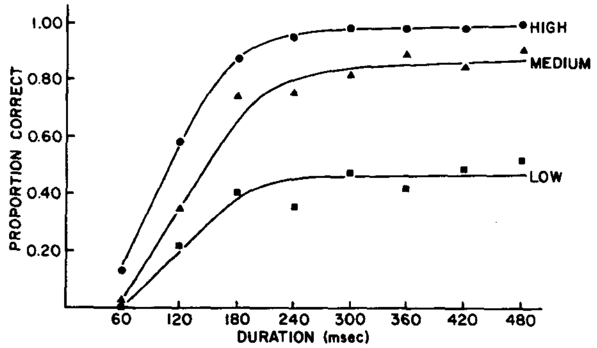

Figure 1. Proportion of correct detections during tachistoscopic viewing of nodules categorized as high, medium, and low in visibility. See text (Experiment 2) for the combination of visibility ratings.

Experiment 2 showed that the detection of directly viewed nodules is affected by the visibility rating of the nodule in the anatomical background of the chest and by exposure duration. Tachistoscopic viewing prevented comparative scanning. How are these findings related to a free-search condition in which nodule location is not specified to the radiologist? Does comparative scanning precede decisions about nodule presence, especially for nodules with low visibility ratings? In order to answer these questions, eye movements and fixations were recorded while radiologists searched a subset of these films for nodules.

EXPERIMENT 3: SCANNING DURING VISUAL SEARCH FOR NODULES

Method

Subjects. Four male radiologists with normal vision, from the Temple University Department of Radiology, served as volunteer subjects. None had served in Experiment 1 or Experiment 2.

Stimuli. Ten of the 35-mm slide copies from Experiment 2 were selected. Four slides were of normal films, two of a man and two of a woman; six slides were copies of abnormal films, three of each sex. Two of the abnormal copies were of films with nodules rated high in visibility, two with nodules of medium visibility, and one each of visibility ratings medium-low and low.

Apparatus. The projectors, viewscreen, and seating arrangement were the same as in Experiment 2. Eye movements and fixations were recorded by a corneal reflection technique using a set of glasses (Narco-Biosystems) interfaced to a PDP-11/40 minicomputer. Details of the system for data collection, correction, and differentiation of fixations from eye movements are reported elsewhere (Carmody, Kundel, & Nodine, 1980). The accuracy of fixations recorded by this system is 1.0 deg when the calibration prior to data collection is screened for an accuracy of 1.0 deg or less. Stimuli were projected onto a rear-projection screen via the three projectors: Channel 1 displayed the calibration slide for pre- and posttrial calibration, Channel 2, a preeposure cross, and Channel 3, the chest images.

Procedure. The recording system was calibrated for the subject's eye position before and after each trial. Following pretrial calibration, the subject fixated a preexposure cross for 2 sec and then viewed a chest image. If the subject found a nodule, he pressed a key to end the trial; otherwise, trials ended after 10 sec and the calibration slide was shown for posttrial calibration. The subjects rated the confidence of their positive decisions as high, medium, or low.

The subjects viewed all 10 images once in each of six sessions for a total of 240 trials. The subjects were aware of the mixture of abnormal and normal chest images and that abnormal images contained only one nodule.

Results

All eye behavior records were examined for a calibration accuracy of 1.0 deg; of 144 trials on nodule images, 136 met this requirement. Of these, 6 represented false positive decisions and were not included, leaving 130 records for analysis. The eye-behavior records were examined for comparative scans, which were defined as fixations on the nodule, followed by a saccade of at least 5 deg to other film areas, and then a refixation of the nodule.

For high-, moderate-, and low-confidence true positive decisions, 19%, 55%, and 83%, respectively, of the nodules received comparative scans; of the nodules that were fixated and not reported, 86% received comparative scans, suggesting that a potential abnormality was recognized but that a decision was made not to report it.

Nodule visibility rating was related to the probability of a comparative scan, as illustrated in Figure 2. The probability of detection during direct viewing (Experiment 2) for these same six nodules is also presented. As visibility rating increased, nodules were found more often in direct viewing and with fewer comparative scans during free search.

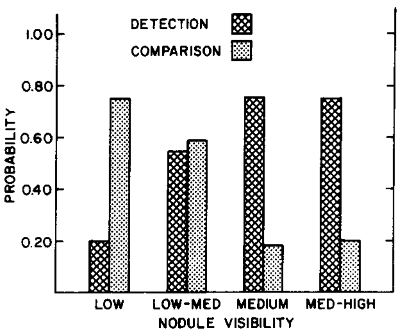

Figure 2. Probability of detection during tachistoscopic viewing (Experiment 2), and probability of a comparative scan during free search (Experiment 3) for nodules of different visibility ratings.

The 96 trials on normal images were examined for a baseline rate of comparative scans when no nodules were present. In the records of 94 trials that met the calibration accuracy of 1.0 deg, 3,459 saccadic eye movements were analyzed. A total of 59 movements met the requirement of fixation on any area, followed by a saccade of at least 5 deg, and then a refixation of that area within 3 deg. Therefore, it is estimated that 1.7% of the scans given to normal images would be similar to the comparative scans given to nodules. This baseline comparative scan rate is much less than the 19%-86% rates given to nodules that were fixated.

GENERAL DISCUSSION

Finding and reporting lung nodules contained on chest X-ray films was influenced by the visibility of the nodule against the anatomical surround and by the scanning strategies used by the radiologist. Although all of the test-series nodules were recognized by the subjects who rated the visibility of nodules, these same abnormalities were often overlooked and not reported during free search. When radiologists fixated nodules under tachistoscopic presentation, detection accuracy was reliably related to (1) the visibility of the nodule "signal" against the anatomical background "noise" and (2) the exposure duration of the X-ray image. As nodule visibility was reduced, detection accuracy decreased to 50%, although radiologists fixated the nodule for durations as long as 480 msec. Detection accuracy did not improve with tachistoscopic durations longer than 180 msec regardless of the visibility of the nodule. Apparently, the information required by the radiologist to resolve suspected nodules was not contained in the area of the chest that embedded the nodule. Rather, this information had to be acquired by fixating features of the normal structures and using these features as a reference for comparison.

Analyses of the visual scanning patterns during free search for the same nodules showed that comparative visual scans precede decision-making about suspected nodules. Highly visible nodules were generally reported when first fixated and received relatively few comparative scans. For nodules that were less visible against the background features, the radiologist apparently compared suspected nodules with the normal anatomical structures that might mimic nodules, such as rib endings or blood vessels. When suspected abnormal features were similar to these normal features, there was a series of comparative scans, from nodule to normal features to nodule. When nodule features were very dissimilar to the background, less comparing was needed before reporting the nodule. Thus, confusability of the signal and noise elements (Estes, 1972) affected scanning: The higher the overlap of signal and noise features, the higher the frequency of comparative scans preceding decision-making.

The comparative scanning strategy was typical in the eye-behavior records of radiologists looking at chest X-ray films, and prevention of this strategy interfered with the ability of the radiologist to discriminate nodules from normal structures (Carmody et al., 1980b). Llewellyn-Thomas (1969) suggested that blackening out of areas viewed would ensure scanning coverage. But our studies suggest that radiologists modify their decision-making criteria to fit the set of specific normal features seen on individual chest films. Thus, nodule detection depends on seeing the normal as well as the abnormal features of the chest contained on the X-ray film.

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