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The Influence of Expertise on X-Ray Image Processing

Marina Myles-Worsley and William A. Johnston
University of Utah

Margaret A. Simons
Department of Radiology, University of Utah

Observers with four different levels of radiological experience performed a recognition memory task on slides of faces and chest X-ray films. Half of the X-ray films revealed clinically significant abnormalities and half did not. Recognition memory for faces was uniformly high across all levels of radiological experience. Memory for abnormal X-ray films increased with radiological experience and, for the most experienced radiologists, was equivalent to memory for faces. Surprisingly, recognition memory for normal films actually decreased with radiological experience from above chance to a chance level. These results indicate that radiological expertise is associated with selective processing of clinically relevant abnormalities in X-ray images. Expert radiologists appear to process X-ray images the way that we all process faces, by quickly detecting and devoting processing resources to features that distinguish one stimulus from another. However, the selective processing of X-ray films appears to be restricted to clinically relevant abnormalities. As they develop the ability to detect these abnormalities, radiologists appear to lose the ability to detect variations in normal features.

This study investigates the relation between expertise and information processing by examining a particular type of expertise, diagnostic radiology, and its effect on the processing of information specific to that domain of expertise, namely, X-ray films. Prior research in other domains of expertise, such as chess (Chase & Simon, 1973), has shown that experts outperform novices when processing tasks are characteristic of those domains. We are not so much interested in demonstrating that expert radiologists are superior to novices in processing X-ray images as we are in determining what perceptual skills make this superior performance possible.

When an experienced radiologist and an untrained observer view the same X-ray image, they presumably perceive it differently even though both receive the same bottom-up sensory input. There is considerable ambiguity in that sensory input because of the low resolution of a radiographic image (e.g., of a chest) compared with a photographic image (e.g., of a face). The bone and tissue silhouettes of the X-ray film are difficult to decipher because they overlap one another in a two-dimensional plane that lacks depth cues. Nevertheless, clearly visible to trained and untrained observers alike are the basic structural features that identify the image as a chest X-ray image: the lungs, heart, and ribs. Although the novice is likely to see only these obvious structures in a chest X-ray image, the expert radiologist is likely to perceive additional structures such as the individual chambers and great vessels of the heart, the trachea, the bronchi, and the hilar regions of the lungs. Apparently, the expert radiologist is capable of seeing more detailed featural information in an ambiguous radiographic image of a chest than is the novice. It is this particular capability that we sought to explore.

We assume that the knowledge acquired by expert radiologists through training and experience includes a knowledge of what can be considered normal in a chest X-ray image. Without subscribing to any particular theory about how such knowledge might be organized or represented within the cognitive system (e.g., procedural vs. declarative knowledge or instances vs. abstractions), we assume that this knowledge entails expectations about the appearance of a normal chest X-ray image, including what structures are typically present in chest X-ray films, where they are located, and what their normal variations are in terms of shape, size, and contrast. We hypothesize that when radiologists have learned what to expect in a chest X-ray image, they become skilled perceivers capable of more *selective* processing of the X-ray image. Upon viewing such an image, the presence of normal features is confirmed quickly with minimal bottom-up processing, and attentional resources can be promptly directed to abnormal features, particularly those that may signal disease. Thus, compared with less experienced observers, expert radiologists allocate their attention more efficiently, devoting a greater proportion of their processing time and resources to abnormal features of the X-ray image.

Results from picture processing research are consistent with this hypothesis. Friedman (1979) found that when studying pictures of common scenes for a subsequent recognition test, people spend less time processing an expected object than an

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Correspondence concerning this article should be addressed to Marina Myles-Worsley, who is now at the Department of Psychiatry, University of Utah Medical Center, 50 North Medical Drive, Salt Lake City, Utah 84132.

unexpected object (e.g., a refrigerator vs. a fire hydrant in a kitchen scene). Research investigating visual processing of a broad range of pictorial stimuli including photographs (Mackworth & Morandi, 1967), line drawings (Loftus & Mackworth, 1978), cartoon drawings (Nodine, Carmody, & Kundel, 1978), famous paintings (Yarbus, 1967), ambiguous figures (Gale & Findlay, 1983), videotapes of shotputters (Mockel & Heemsoth, 1984), and X-ray films (Kundel & Nodine, 1978) has shown that eye fixations are not distributed randomly over the picture, but rather are concentrated on the less predictable details within the picture.

The idea that attention is directed to atypical details of a visual stimulus may help to explain why people can remember faces so well. Face memory research has shown that faces rated as distinctive or unusual in appearance are better recognized than are faces rated as similar to a prototype (Going & Read, 1974; Light, Kayra-Stuart, & Hollander, 1979). These results suggest that distinguishing features play an important role in face memory. People may have a good memory for faces because when they encounter a face for the first time, they allocate their processing resources efficiently, wasting little time on the expected features that are common to all faces and devoting most of their attention to those features that distinguish one face from another. If selectively attending to the distinguishing features of a face is what characterizes the face-processing expertise that most people possess, then selectively attending to the distinguishing features of a chest X-ray film may be what characterizes the processing expertise that experienced radiologists possess.

In order to examine how perceptual processing of X-ray images changes as a result of experience, observers with different degrees of radiological expertise studied a series of slides, each presented for 500 ms, in preparation for a recognition test. The study task was time limited to accentuate the effects of expertise. If, as hypothesized, experts allocate their processing time and resources more efficiently than less experienced observers, then limiting viewing time to 500 ms should make the perceptual advantages associated with expertise more pronounced. Three types of slides were presented: faces, abnormal chest X-ray films, and normal chest X-ray films. The classification of X-ray films as abnormal versus normal was performed by expert radiologists based on whether or not the films revealed disease-related abnormalities. Because all observers were presumed to be experienced at processing faces, face recognition was used as a benchmark for recognition memory under the specific viewing conditions of this experiment. The purpose of using both normal and abnormal chest X-ray films was to assess the extent to which the presence of a distinctive abnormality would improve recognition memory performance, especially for more experienced radiologists.

Recognition memory for faces was expected to be equivalently high across all levels of radiological expertise because all of the observers were assumed to be expert processors of faces. Recognition memory for both normal and abnormal X-ray films was expected to increase with radiological expertise. Based on the hypothesis that similar perceptual skills underlie both expert face processing and expert X-ray film processing, recognition of chest X-ray films by the most experienced radiologists was expected to approach the recognition level achieved for faces. It was also anticipated that experienced radiologists would be better able to recognize X-ray films that contained clinically relevant abnormalities than ones that did not. This advantage for abnormal over normal X-ray films was expected to increase with radiological experience because the knowledge needed to detect abnormalities is assumed to increase with experience.

Method

Subjects

A total of 33 subjects participated in the experiment: 11 University of Utah undergraduates who served as novices and 22 professionals affiliated with the University of Utah Medical Center Department of Radiology. Of the radiology professionals, 6 were first-year radiology residents with less than 1 year of radiological experience, 7 were junior staff radiologists with an average of 4 years of experience, and 9 were senior radiologists with an average of 22 years of radiological experience.

Stimulus Materials

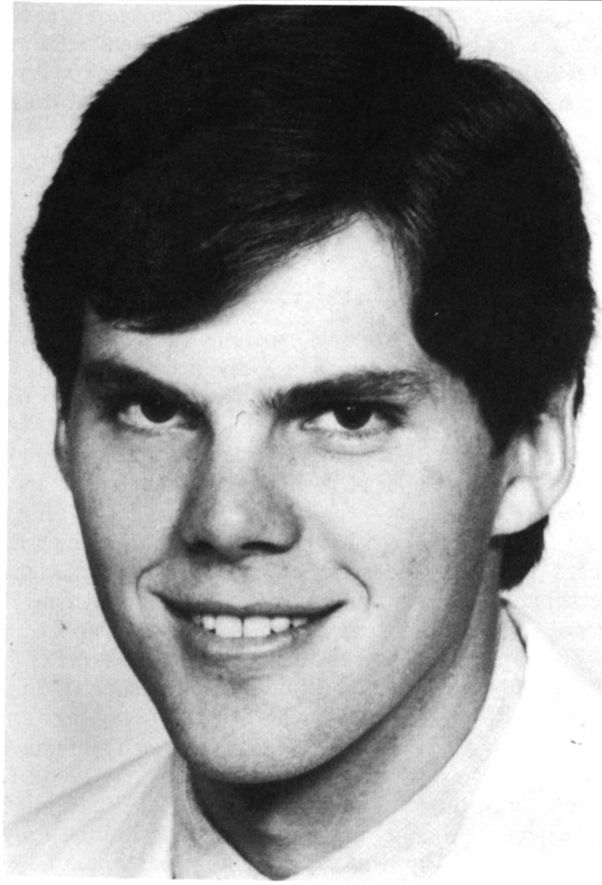
Black and white photographic slides of faces and chest X-ray films were presented to each subject. The faces shown were a randomly selected sample of 40 photographs of third-year University of Utah medical students whom the observers did not know. Posterior/anterior chest X-ray films that had been formally evaluated as normal or abnormal were pulled randomly from the University of Utah Medical Center film library. After a senior staff radiologist had confirmed the normal/abnormal classification of each X-ray film, 20 normal and 20 abnormal films were selected as the chest X-ray stimuli. The abnormal chest films were selected so that each portrayed a unique abnormality not present in any other chest film in the series (e.g., congestive heart failure, right lung collapse, pneumonia). Examples of the face and X-ray film stimuli are presented in Figure 1.

Procedure

The experimental sessions were conducted at the University of Utah Medical Center. Subjects were seated in a darkened observer booth approximately 1 m from a 20 cm × 30 cm rear projection screen located at eye level. A series of slides was presented to subjects by using a microprocessor-controlled Kodak Carousel slide projector.

In the study phase, 20 chest X-ray films (10 normal and 10 abnormal) randomly interspersed with 20 faces were presented at the rate of one slide per second, each for a duration of 500 ms. The visual angle subtended by the display was about 25° horizontally and 33° vertically. Subjects were instructed to "look at each slide carefully; you will later be tested for which slides you remember seeing."

The test phase began after a 1-min period. In the test phase, the study set of 40 slides was combined with 20 new chest X-ray films (10 normal and 10 abnormal) and 20 new faces, and these 80 slides were presented one at a time in random order. The assignment of slides to the old and new sets was counterbalanced across subjects. The exposure duration was determined by the subject's latency of response. Subjects were instructed to press a button marked *old* if the slide had appeared in the study phase and a button marked *new* if the slide had not been presented earlier. The old/new judgements were recorded by a Data General Eclipse S250 computer.



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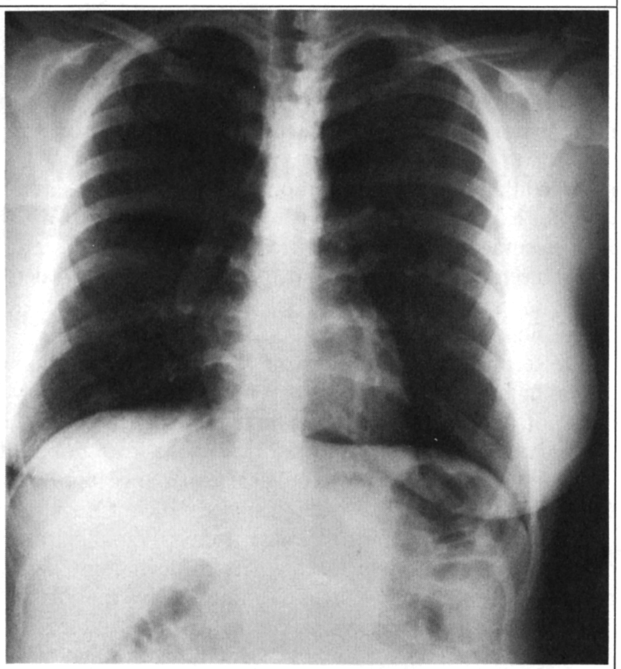

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Figure 1. Examples of face (A) and normal chest X-ray film (B) stimuli.

Results

The proportion of old slides called old (hits) and the proportion of new slides called old (false alarms) were calculated for faces, abnormal X-ray films, and normal X-ray films. Measures of recognition memory performance were computed from the hit rates and the false alarm rates. Our principal unit of analysis was the probability of a hit minus the probability of a false alarm (hits-false alarms), which we refer to as recognition accuracy. Signal detection measures of memory sensitivity (d') and response criterion (β) were also computed. Mean values of these measures are presented in Table 1.

Recognition accuracy was selected as the principal unit of analysis because this measure is a relatively straightforward, easily interpreted index of overall recognition performance. A 4 × 3 mixed-design analysis of variance with radiological experience (novices, residents, junior radiologists, and senior radiologists) as a between-subjects factor and stimulus type (faces, abnormal X-ray films, and normal X-ray films) as a within-subjects factor was performed on the recognition accuracy data. The main effect of stimulus type was highly reliable, $F(2, 58) = 23.30$, $MS_e = .038$, $p < .001$. More important, the effect of stimulus type interacted with level of expertise, $F(6, 58) = 2.62$, $MS_e = .038$, $p < .05$. The nature of the interaction is evident in Figure 2: As radiological experience increased, memory remained consistently high for faces, increased for abnormal X-ray films, and actually de-

Table 1
Hit Rate (H), False Alarm Rate (FA), Recognition Accuracy (H-FA), Memory Sensitivity (d′), and Response Criterion (β) for Faces, Abnormal X-Ray Films and Normal X-Ray Films as a Function of Radiological Experience

	Radiological experience				
Measure	Novices	Residents	Junior radiologists	Senior radiologists	Average
			Faces		
H	.614	.742	.664	.650	.659
FA	.195	.292	.186	.260	.229
H − FA	.418**	.450**	.479**	.390**	.429
d'	1.233**	1.313**	1.469**	1.130**	1.269
β	1.499	1.188	1.899	1.212	1.449
			Abnormal X-ray films		
H	.546	.591	.623	.594	.584
FA	.418	.400	.371	.246	.358
H − FA	.127	.193	.251**	.350**	.226
d'	0.362	0.523	0.699**	0.996**	0.635
β	1.384	1.018	1.189	1.209	1.228
			Normal X-ray films		
H	.555	.667	.554	.425	.539
FA	.418	.407	.500	.478	.450
H − FA	.136**	.259**	.054	−.053	.090
d'	0.616*	0.697**	0.124	−0.154	0.316
β	1.020	1.046	1.234	0.783	1.005

* $p < .05$ when the specified mean value was tested against 0.
** $p < .01$ when the specified mean value was tested against 0.

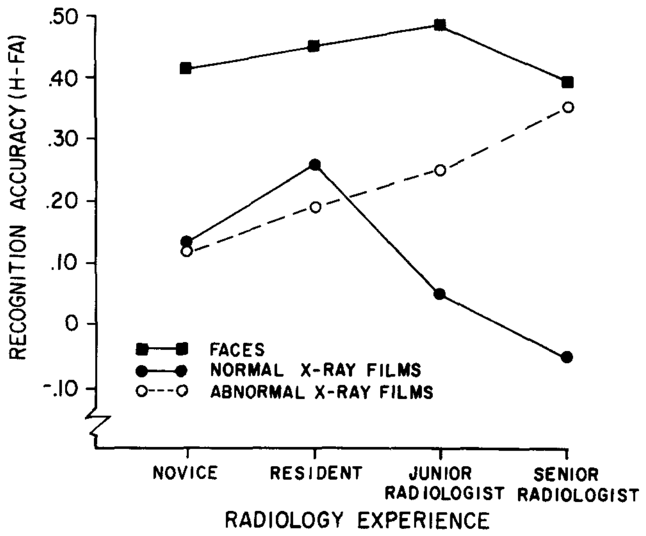

Figure 2. Recognition accuracy (proportion of hits minus proportion of false alarms) for faces, abnormal X-ray films, and normal X-ray films as a function of radiology experience.

creased for normal X-ray films. A post hoc comparison using an appropriate set of contrast coefficients was used to test the significance of these recognition accuracy trends over the four levels of expertise. The comparison was highly significant, $F(1, 58) = 69.42$, $MS_e = .038$, $p < .001$, and accounted for 90.50% of the total variance in the interaction of stimulus type and expertise.

A specific comparison revealed that expert radiologists recognized abnormal X-ray films just as accurately as they and the other observers recognized faces, $t(9) < 1.00$. Residents, on the other hand, showed the same low level of recognition performance on abnormal as on normal chest films, $t(6) < 1.00$, suggesting that they did not selectively process the abnormal features of X-ray images. The results of additional *t* tests performed to determine whether the mean H-FA scores were significantly greater than zero are shown in Table 1. All four groups showed highly significant levels of recognition accuracy for faces. In the case of abnormal X-ray films, the two lowest recognition accuracy values, those for novices and residents, failed to exceed chance, possibly because of high variability and small sample sizes, $t(11) = 1.50$, $SE = .269$, *ns* for novices; $t(6) = 1.74$, $SE = .249$, *ns* for residents. The effect of radiological experience was more clear cut in the case of normal X-ray films. Recognition accuracy dropped from above chance levels for novices, $t(11) = 2.62$, $SE = .163$, $p < .01$, and residents, $t(6) = 3.55$, $SE = .162$, $p < .01$; and to chance levels for junior radiologists, $t(7) = 0.54$, $SE = .246$, *ns*, and senior radiologists, $t(9) = 0.86$, $SE = .175$, *ns*.

Analyses of d' showed the same trends and the same general patterns of significance as those reported for the recognition accuracy scores (see Table 1). A 4 × 3 analysis of variance of the β scores indicated that response criteria were similar across the four groups of subjects, $F(3, 29) = 1.99$, $MS_e = .137$, *ns*, and did not depend upon the presence or absence of an abnormality in an X-ray film, $F(1, 29) = 2.52$, $MS_e = .200$, *ns*. The only reliable effect was for stimulus type, $F(2, 58) = 5.45$, $MS_e = .200$, $p < .01$. A Newman-Keuls test confirmed that the response criterion was more conservative for faces (1.449) than for either abnormal chest films (1.228) or normal chest films (1.005). The stimulus type by expertise interaction failed to reach significance, $F(6, 58) < 1.00$, $MS_e = .266$, indicating that the effects of radiological experience on the recognition of X-ray films were not confounded by variations in response criterion.

Discussion

The purpose of the present experiment was to examine the role of radiological expertise in X-ray image perception. Observers with varying degrees of radiological experience viewed briefly exposed slides of normal and abnormal chest X-ray films intermingled with slides of faces and then performed a recognition memory test. There were two key results. First, as expected, recognition memory for abnormal X-ray films increased with radiological experience to the same high level that was observed for faces. Second, contrary to expectation, recognition memory for normal X-ray films actually decreased with radiological experience to a chance level.

The first finding is consistent with the well established finding, referred to in the introduction, that attention is captured by unexpected elements of familiar scenes or stimulus arrays (e.g., Friedman, 1979), even when stimulus exposure time is very brief (e.g., Myles-Worsley, 1986). Obviously, a perturbation in an array can be identified only to the extent that the normal, unperturbed form of the array is represented in knowledge, a condition that is satisfied by prolonged experience with the array. Thus, as radiologists acquire more knowledge about the normal appearance of X-ray films, they may begin to detect quickly and automatically any abnormalities in these films. Just as attention to an atypical feature in a face can render the face memorable, so attention to an abnormality in an X-ray film can render the film memorable. The radiology literature provides some support for this line of reasoning. Kundel and Nodine (1975) observed that a single eye fixation (200-ms exposure) is sufficient for experienced radiologists to detect and identify, with 70% accuracy, major pathological features. More recently, Christensen et al. (1981) found that time required to detect X-ray abnormalities decreased as a function of radiological experience.

The second key finding reveals that the foregoing line of reasoning must be tempered by an important qualification. It does not appear to be the case that radiological experience renders observers sensitive to *any* deviations from normality in X-ray films. Instead, radiological experience appears to sensitize observers only to clinically significant deviations, namely, those that indicate disease. Indeed, radiological experience appears to reduce sensitivity to deviations that are not clinically significant. This is indicated by the fact that radiological experience was accompanied by a reduction in recognition memory for normal X-ray films from an above-chance level to a chance level. Distinctive features in the normal films (e.g., photographic blemishes or relatively large ribs) that were to some degree noticed by novices apparently went completely unnoticed by the most experienced radiologists. This suggests that the general tendency to attend to any abnormalities in an otherwise familiar image can be modulated by extended practice at searching for particular abnormalities.

In summary, the present findings suggest that radiological expertise is based on two kinds of knowledge: knowledge of the characteristic features of clinically normal exemplars of a class of X-ray film (e.g., chest films), and knowledge of the particular set of uncharacteristic features that signal pathology. The first kind of knowledge allows for the swift and automatic processing of the normal features of X-ray films, and the second kind of knowledge permits the quick detection of pathologies. Together, these two kinds of knowledge can account for our two key findings. Radiological experience improves memory for abnormal films because it improves the likelihood of detection of the abnormal features that distinguish these films from one another and from normal films. On the other hand, radiological experience reduces memory for X-ray films that do not reveal pathologies because the search for particular disease-related abnormalities reduces the likelihood of detecting other, more innocuous abnormalities. Thus, expertise in a particular domain is likely to be a two-edged sword: It can bias perception toward some classes of stimuli in that domain and away from others.

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