A Comparative Research in Medical Image Visual Searching of Novice, Proficient and Expert Radiologists: Evidence from Eye Movement

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Abstract. This article is to discuss the radiologist' fixation characteristics and processing strategies in medical image searching, and to find out the expert advantages and characteristics, in order to provide theoretical basis for improving the ability of novice and proficient radiologist. SMI250 eye tracker was used to record participants' eye movements on the X-ray film of chest. Fifty subjects were divided into three groups: 17 experts,17 proficient and 16 novices. Eye movement was observed and analyzed, The $\chi 2$ or t test were used for statistical analysis. The results showed that false negative rate (FNR) of experts was lower than that of proficient or novices. There are more types of simple –mode scan pattern in the expert group than in the proficient or novice ($P<0.05$). Besides, experts exhibited a number of characteristics associated with efficient scan paths, including fewer fixation counts, less total fixation duration, longer saccadic amplitude, faster in arriving at the nodule. For conclusion, compared with novices and proficient, expert radiologist can find out the target quickly and accurately, showing superior perceptual advantage. Experts tended to make decision-making error, while the novice tended to scanning-error and proficient to recognition-error.

Introduction

Lung cancer has become the most common malignant tumor and has a high death rate. Its five-year survival rate is 12%~15%, then that of early stage of lung cancer is 70% ~ 80%, so early screening will improve the survival rate of patients with lung cancer[1-2]. It is the first choice of screening for lung cancer with chest X-ray film, that is the low price and weak radiation dose, but there are a rather high rate of missed diagnosis [3-6], which not only affects the patient's treatment, but also affects the personal reputation of doctor, and results in the medical disputes. How to cause the high rate of missed diagnosis? Recent research [7,8] demonstrates that the "human error" is the main factor, including the bias of the doctor's attention and the wrong search strategy. Kundel et al [7] have pioneered the study field of using the eye movement technology to discuss the causes of missing reports in medical imaging. In this study, chest X-ray as the observation object, eye movement differences of experts, proficient and novices were compared on detecting pulmonary nodule, as well as the cause of missed diagnosis was discussed.

Method

Participants. 50 radiologists were divided into 3 groups: 17 experts, 17 proficient and 16 novices. Experts were associate-chief physicians with clinical experience of more than 10 years from a hospital (Grade A of three-class) of Fujian Province. Proficient were physicians with clinical experience of 2-5 years in the same hospital. Novices were medical imaging students having practiced in the department of radiology for over 6 months. There are 14 males and 3 females in

expert group, with mean age of 41.71±4.03 years old, mean clinical experience of 21.59±4.74 years; 13 males and 4 females in proficient group, with mean age of 28.11±1.05 years old, mean clinical experience of 3.18 ±113 years; 10 males and 6 females in novice group, with mean age of 23.13±0.50 years old. All of the subjects were normal vision or corrected vision, without eye disease, no color weakness or color blindness.

Experimental Materials. There are 78 films of chest, of which 40 normal, 38 with nodules (CT scan verification). The nodules were solitary lesion with 5-20mm in diameter, clear boundary, low-density and no calcified. Evaluation of the significance of nodules: 3 experts combined with the results of CT examination, 38 nodules in X-ray of chest were evaluated into 5 scales on the salience, the "1" represents not salient, "5" represents very salient. Finally, there are 13 cases in the low salient nodules, 10 in the middle and 15 in the high.

Experimental Instrument. SMI250 eye tracker was used, with 500Hz of sampling frequency and binocular infrared tracking. Showing stimulation were on the 19 inches display TFT LCD, with 100Hz of refresh rate, 1280 x 1024 pixels of resolution. Experimental procedures was programmed by iView 2.5.

Experimental Design. Experiment used 3 (Level of Expertise: expert, proficient and novice) × 3 (nodule salience. low, medium and high) mixed design. The parameters include the fixation counts, the total fixation duration, the average saccade amplitude and scan path. 9 conditions created by the 3× 3 factorial combination of level of expertise (expert, proficient, novice) and types of nodule salience(low, medium, high).Eye movement metrics of the whole image include the fixation counts, total fixation duration, average saccade amplitude. In this experiment, 5mm around the nodule is defined as area of interest（AOI）[9,10].Metrics of the nodule include time to first hit, dwell time, dwell time percent of AOI, fixation count, fixation count percent of AOI.

Experimental Procedures and Data Analysis. Participants sat about 60 cm away from the monitor. Before experiment, they were given the instructions, eye calibration and 4 practices, until they had fully understood the experimental operation. After the experiment, the faulty data were deleted and effective data were collected with the Microsoft Excel and statistical analysis of χ^2 or *t* test was done with Spss17.0 software.

Results

Visual Search Performance Comparison. False-negative rate of expert, proficient and novice was 10.53%, 14.09% and 21.22% respectively, which showed statistically significant difference (Table1,P<0.05). Expert, proficient and novice in low and middle salient nodule omission rate was statistically significant difference (P<0.05), but in high salient nodule omission rate was not statistically significant difference (P>0.05).Classification of missing diagnosis showed in Table 2, and there is statistically significant difference among three groups.

Table 1 Missing diagnosis and comparison of three groups in observing the 38 nodules

Classification of nodules	High （15）	Meddle （13）	Low （10）	Sum (38)
Experts (17)	0 (0)	10(4.52%)	58（34 12%）	68（10 53%）
Proficients (17)	2(0.78%)	23(10.41%)	66（38 82%）	91（14 09%）
Novices (16)	5(2.08%)	40(19.23%)	85（53 13%）	129（21 22%）

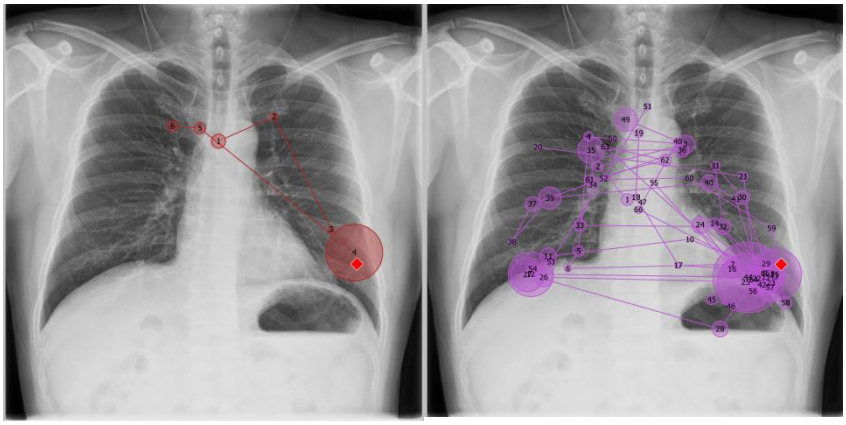
$\chi 2$=9.963 P=0.041

Table 2 Classification of missed diagnosis on nodules

Level of Expertise	Expert	Proficient	Novice
Scanning errors	13（19.11%）	18（19.78%）	53（41.41%）
recognition errors	24（35.29%）	39（42.85%）	39（30.47%）
decision-making errors	31（45.59%）	34（37.36%）	36（28.13%）

$\chi 2$ =22.44 P=0.000

Eye Movement data and Comparison. Fixation distribution show the scan pattern of participants watching the same x-ray film of chest (Fig. 2). Scanning pattern is divided into: simple type (single circular and scanning, repeat no more than 1/2 circumference) and complex type (random or more circular scanning, repeated more than 1/2 circumference). Experts appeared the repeat scanning area in the order of the nipple, hilum and apex. Proficient appeared in the order of the hilum, apex and nipple. Novice appeared no obvious characteristics in the order. Eye scanning track types showed and comparison, statistics showed that experts in a simple type, there was significant difference compared with proficient and novice (Table 3, P<0.05).



scan pattern: simple type(A) and complex type(B)

Table 3 Analysis and comparison of scan pattern

Scan type	Simple	Complex
Expert	95	41
Proficient	77	54
Novice	41	87

$\chi 2$=39.82 P=0.000

Eye Movement Data and Comparison. Scanning the scene on the nodule and the normal, participants needed longer time on the normal lung than the nodule (Table 4), and the number of fixation counts and total fixation duration of expert were fewer than proficient and novice, and saccade amplitude was larger. participants spent more fixation counts and total fixation duration and longer saccade amplitude in low-significant nodules (Table5, P<0 05).

Table 4 Comparison and the parameters about observing the normal and nodule

Level of Expertise		Expert	Proficient	Novice	F	P
FC	nodule	9.38±1 61	13.81±3 69	19.87±3 71	12.21	0.00
	nomal	17.86±5.04	24.67±6.44	36.89±6.82	8.09	0.00
TFD(s)	nodule	3.27±0.68	4.64±1.13	6.72±1 60	11.90	0.00
	nomal	5.59±1 38	7.73±2 22	11.95±2.59	8.61	0.01
ASA	nodule	5.75±0 58	5.14±0 60	4.72±0.69	11.21	0.00
(°)	nomal	5.87±0 70	5.16±0 72	4.49±0.69	15.66	0.00

Notes: fixation count= FC, F=67.76,P=0.00 (between normal and nodule); Total fixation duration =TFD, F=53.84, P=0.00 (between normal and nodule); Average saccade amplitude =ASA, F=0.13, P=0.72 (between normal and nodule);

Table 5 The overall fixation parameters of images with different salient nodules

Level of Expertise		Expert	Proficient	Novice
FC	low	14.71±3.18	20.71±4.23	29.06±5.21
	middle	8.94±1.43	14.01±3.81	21.98±4.47
	high	6.20±0.63	9.02±3.56	12.07±4.21
TFD(s)	low	5.22±1.54	7.03±1.81	9.82±1.96
	middle	3.21±0.59	4.84±1.55	7.61±1.58
	high	2.03±0 31	2.86±0 53	3.89±0.92
ASA (°)	low	5.66±0 85	5.19±0 81	4.61±0.72
	middle	5.43±0.69	5.11±0.73	4.49±0.70
	high	6.10±0.91	5.13±0.73	5.00±1.03

Notes: fixation count =FC, F=13.03, P=0.00(comparison in the different experience);F=115.53, P=0.00(comparison in the different nodules); Total fixation duration=TFD, F=12.22, P=0.00; (comparison in the different experience); F=101.68, P=0.000 (comparison in the different nodules); Average saccade amplitude=ASA, F=11.24, P=0.00(comparison in the different experience); F=4.80, P=0.03 (comparison in the different nodules).

Table 6 The fixation parameters of different salient nodules(AOI)

Level of Expertise		Expert	Proficient	Novice
TFH（s）	low	1.48±0.46	2.09±0.45	2.54±0.52
	middle	0.84±0.20	1.03±0.22	1.96±0.66
	high	0.48±0.08	0.56±0.11	0.89±0.39
FC	low	2.49±0.82	3.21±0.94	3.07±0.87
	middle	2.82±0.67	3.50±0.95	3.80±0.86
	high	2.05±0.65	2.90±0.81	3.43±1.05
FCPA（%）	low	17.19±3.60	16.18±2.88	11.78±2.57
	middle	29.30±4.18	29.67±4.50	23.76±5.05
	high	33.74±4.21	34.88±5.39	33.15±4.64
DT（ms）	low	1.15±0.36	1.17±0.28	1.07±0.33
	middle	1. 3±0.23	1.35±0.31	1.33±0.28
	high	0.80±0.17	0.94±0.22	1.06±0.26
DPTA（%）	low	24.40±3.08	17.95±2.44	12.33±2.67
	middle	39.83±4.52	34.64±6.41	24.25±4.38
	high	42.96±3.76	38.44±6.16	33.66±5.15

Notes：time to first hit=TFH, F=14.11, P=0.000 (comparison in the different experience); F=119 37, P=0.00(comparison in the different nodules); fixation count= FC, F=2.37, P=0.10 (comparison in the different experience); F=0.24, P=0.63(comparison in the different nodules); Fixation Count Percent of AOI=FCPA, F=1.48, P=0.24(comparison in the different experience); F=268.61, P=0.000 (comparison in the different nodules). Dwell time=DT, F=0.22, P=0.79 (comparison in the different experience); F=4.46, P=0.04(comparison in the different nodules); Dwell time percent of AOI=DPTA, F=10.26, P=0.000(comparison in the different experience); F=243.55, P=0.000 (comparison in the different nodules).

Discussion

Clinical Experience and Visual Search. There are significant differences in the visual search between expert and novice or proficient, including fixation counts, total fixation duration, scan pattern and so on. Scan pattern show the original knowledge and clinical experience will have effect on the visual search and attention distribution of medical image. Experts spend less time in finding the nodule and information processing, while inexperienced doctors often spend more time covering the image area and fixating on the nodule. The fixation of the AOI showed that experts spent less fixation counts on nodules than proficient or novice, but the rate of fixation count of AOI is higher than proficient or novice. Also, experts spent less dwell time on nodules than proficient or novice, but the dwell time percent of AOI is higher than proficient or novice. Experts can process the information efficiency, which is in accordance with research results [11]. Observing the area of interest, experts can find and fixate the nodule with short time, but the time will be longer in low significant nodule than the high. In the visual search experiment, it appear that expert arrive at the nodule quickly. They will get the visual stimuli as a whole, and may quickly deviate from the abnormal in the pictures. Swensson [12] believes that experts, after a large number of clinical practices, will have developed a unique perception mechanism. That is, when viewing the image a

glance, experts can automatically filter out the normal characteristics, and may directly appear the abnormal target position. So experts had the characteristics of speed in medical image search, and can have fast classification on the medical images. The reaction is more accurate and faster, while novices rely more on exploratory search, so their scanning time is long and error rate is high.

Medical Imaging Scanning and Searching Strategy. The saccade amplitude of expert is larger than that of novice or proficient, it reflects the experts can perceive more meaningful scan pattern. Their eyes can sweep wider and have a stronger ability to use peripheral vision. Combined with scan pattern, we can see that the expert's visual search is more efficient and concise. The experts can quickly look at one of lung abnormalities, then crossed the other lung, and fixate the nodule. Experts can use a wide range of saccades to scan the wide range image, and quickly detect the anomalies. There is no doubt that peripheral vision plays a key role in guiding search. These results can be explained, because experts have rich clinical experience and knowledge, and they have stored in mind a lot of normal and abnormal images; while novices are slower in observing the images. They are more likely to have a search with the mode of system information. Study on the medical expertise indicates that the diagnostic ability of experts was determined by their knowledge content and structures [13]. In the mind of expert, knowledge is organized in the form of “disease script” and stores a large number of previously diagnosed samples. With the increase in clinical experience, physician in the mind to establish some of symptoms associated with diagnosis and typical patient, which was called "disease scripts". Experts get the diagnosis information at the early stages as the correct script, which may be a potential cause of having the diagnostic skills.

Influence Factor of Visual Searching. Studies have shown that significant differences of nodule have an impact on the diagnosis accuracy and search speed [14]. Our results suggest that experts fund the middle and low significant nodule with lower false negative rate than proficient or novice, but fund the high significant nodule was no significant difference. In other words, experts have less difficulty in searching nodule, the advantage of experts is reflected in searching the nodule with higher difficulty. It is obvious that nodule with higher difficulty can be the main index to test the difference among three groups. Therefore, it can be said that, in the process of growth from novice to experts, whose different mainly reflected in the identification of high difficult nodule. By observing the eye movement of searching, relative to the proficient and novice, experts have fewer fixation count, shorter total fixation duration and larger saccade amplitude on the middle and low significant nodule, and have a higher efficiency. Kundel [15] pointed out that the success of the detection of pulmonary nodules depends on the significant degree of pulmonary nodules. Bertram and other [8] study found that, for different difficulty of the experimental tasks, subjects do not always show the same eye movement. Our results found that their false-negative rate, fixation count and total fixation duration increased with decreasing of nodules significant, which indicated that the difficulty of image increases, the search will need more times to refine and analyze, and more attention to be assigned to the information processing. The minimum saccade amplitude was fund in the images of low-significant nodule, it reflects the gaze pattern of watching carefully.

Visual Search and Error Types. This study found that the expert, proficient and novice have a different false-negative error type in visual searching. Expert tends to decision-making errors, proficient tends to recognition errors and novice tends to scanning errors. Under the condition of low significant nodule, there is the significant difference in three groups; under the condition of middle significant nodule, there was no significant difference in three groups. This shows that in different nodules conditions, experts, proficients and novices do not always show the same type of omission-errors. Knowledge and experience of physician will affect the imaging searching, physicians don not have the same type of omission-report. Our study extends the research scope of authors Kundel, Donovan and Litchfield [3,7]. What are the causes of the missed diagnosis of X-ray? Early researchers believe that decision-making in radiology is inherent, so the misdiagnosis is inevitable, that the method to reduce the misdiagnosis should improve the image quality [7,8]. Later, more and more researchers have proved that the "human error" is the main factor in the missed diagnosis of radiology, which is caused by the error of the information processing [11]. The results show that detection of nodules need to the judgment and understanding from the physician, and the

novice needs to increase the clinical experience, the knowledge of local anatomy and pathology. In clinical practice, due to the increase of medical disputes or image fuzzy information, many physicians are increasingly inclined to false positive reports. Our study found that experts have found the position of nodules, and stared for some time at the nodule position, but eventually made a negative diagnosis to the true nodule. That suggests experts have a cautious decision-making tendency, which is a new subject that we need to study in the future.

Summary

Experts are better than the proficients and novices in search performance with greater advantages and high efficiency. experts exhibit a number of the characteristics associated with efficient scan paths, including fewer fixation counts, less total fixation duration, larger saccadic amplitude, arriving at the nodules faster than the proficients and novices. Expert have concise and efficient scanning mode.They have the advantages of wild perceptual area in small scan path. All of expert, novice and proficient will spent more time when the nodules decrease its significance, and the saccade amplitude will become smaller. On the type of missed diagnosis, expert tends to the decision-error, while proficient tends to the identify-error and novice to the scan-error.

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