

Characteristics of the Reciprocal Movement of Radiographers' Gaze Based on a Comparison of Entry-Level and Experienced Radiographers

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Abstract

With the development of AI, AI may substitute for physicians in radiological interpretations in the future. The purpose of this paper is to identify factors that could form the foundation for algorithms enabling AI to explore pathological findings. This study focuses on the "angles of gaze trajectory" and "average speeds of gaze movement," and conducts a comparative analysis between entry-level and experienced radiographers. Firstly, based on the results of angles of gaze movement, experienced radiographers exhibited frequent movements around the 180-degree mark compared to entry-level radiographer. Both entry-level and experienced radiographers commonly displayed frequent movements around 0 degrees and near 350 degrees. Secondly, according to the results of average speeds of gaze movement, entry-level radiographers were found to have faster movement speeds compared to experienced radiographers.

Keywords: Eye-Tracking, Angles of Eye Trajectory, Artificial Intelligence (AI)

1. Introduction

Machine learning and deep learning advancements, coupled with high-performance GPUs, have led to a significant breakthrough in the field of artificial intelligence [1]. Particularly in image recognition, AI is considered to surpass human capabilities [2]. In the healthcare sector, there is a clear demonstration of AI's image recognition capabilities, particularly in the interpretation of CT scans. Given the current shortage of radiologists, there is growing anticipation for AI to reach a level of proficiency in image interpretation that could serve as a viable substitute for human physicians. To achieve this capability, it is crucial to identify various factors contributing to the training of AI in image interpretation. One such factor is the analysis of physicians' eye movements during image interpretation. This paper aims to explore the importance of physicians' gaze patterns as a contributing factor, underscoring the necessity to uncover and comprehend these aspects to enhance the AI learning process in image interpretation.

2. Previous Research

Numerous studies have explored gaze measurements of physicians during the interpretation of radiographic images, a certain cue is presented on the screen, and an analysis is

conducted on how participants can detect this cue in terms of gaze trajectory and movement velocity [3]. Studies comparing the gaze patterns of novices and veterans are also prevalent. For instance, an analysis of gaze fixation points during chest X-ray image interpretation shows that experts promptly identify lesions and repeatedly confirm their presence while also scanning other areas, whereas novices tend to fixate on structurally complex regions [4]. In research on overlooking and missing findings during medical image interpretation, it has been demonstrated that experts thoroughly observe photographs, strongly focusing on the accurate location of anomalies, while novices exhibit more inconsistent observation patterns, with their gaze often diverted to complex positions where organs overlap [5]. This line of research on tacit knowledge and expertise in skill-demanding scenarios has unveiled that veterans and novices differ in terms of "where to look," influencing their subsequent performance [6]. As a preliminary step, it is necessary to extract and quantitatively analyze the gaze patterns of experts before linguistically formulating such characteristics. Therefore, the purpose of this paper is to conduct a comparative analysis between entry-level and experienced radiographers regarding the angles of gaze trajectories, which could serve as the foundation for algorithms exploring findings in artificial intelligence (AI).

Furthermore, the objective is to propose recommendations for AI to learn from the disparities in gaze trajectories between entry-level and experienced radiographers, ultimately enabling more accurate and effective image diagnostics in the future.

3. Experiment

The gaze measurement experiment was carried out as follows.

- **Participants:** One experienced radiographer (with over 10 years of experience) and one entry-level radiographer (with 1~3 years of experience).
- **Data:** 15 cases with abnormal findings, 15 cases without abnormal findings
- **Experimental Method:** Tobii Pro Lab eye-tracking software was employed. The camera was fixed. Participants were presented with CT images on a computer screen and performed interpretation of CT images by scrolling through the images using a mouse, following their usual reading methods.

4. Analysis Methods

Duchowski provides guidelines regarding data collection and interpretation in the context of eye tracking. The book introduces applications and instances of success in fields such as medicine, psychology, and human factors engineering, underscoring the effectiveness of employing eye tracking in the medical domain [7]. Furthermore, Holmqvist et al. offer an in-depth exposition of data analysis methods in eye tracking research. Of particular note, fixation points serve as a frequently employed metric [8]. However, the analyzed metric in this paper is the angle of the gaze movement as it sequentially moves from one fixation point to the next in succession. (Henceforth, this shall be referred to the angle of eye movement.) The reason for this is to confirm whether the direction of eye movement, namely the trajectory of the gaze, when radiologists interpret CT images is consistent with the characteristics of everyday human gaze as elucidated in previous research [9]. The characteristics of human eye movement elucidated in this previous research are detailed in the subsequent discussion section. The employed eye-tracking software in this study automatically aggregates parameters such as fixation points, fixation counts, fixation duration, and coordinates of fixation points, subsequently generating this information as output data. The trajectories connecting successive fixation points (hereinafter referred to as gaze trajectories) are visually indicated by red lines, enabling direct observation.

The angles of gaze movement were defined based on the eye-tracking data obtained using Tobii Pro Lab and analyzed using a custom-developed program. In this context, angles of gaze movement refer to the direction changes of gaze trajectories as it progresses across different fixation points. The concept is illustrated in the Fig. 1, where black circles represent fixation points (pixel), and connecting lines depict the gaze trajectory between these points. When the coordinate shifts from (971, 810) to (988, 867), and subsequently to (974, 816), the angle of gaze movement is denoted by Angle 1 in Fig. 1. The directional movement is measured clockwise. Similarly, when moving from (988, 867) to (974, 816) and further to (1013, 837), the angle of gaze movement is represented as Angle 2 in Fig. 1.

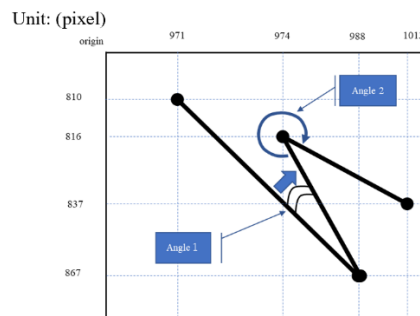


Figure 1: Angles of Gaze Movement

In addition to the angle of gaze movements, the average speeds of gaze movement are calculated. The average speeds of gaze movement are calculated by dividing the distance of gaze movement measured by the device by the elapsed measurement time. The average speeds of gaze movement were calculated for both entry-level and experienced radiographers, separately for cases with and without abnormal findings.

5. Results

The results of gaze angles are depicted in Fig. 2, Fig. 3, Fig. 4, and Fig. 5. Fig. 2 and Fig. 3 present the gaze angle results of experienced individuals. Fig. 2 corresponds to cases with abnormal findings, while Fig. 3 represents cases without abnormal findings. Fig. 4 and Fig. 5 illustrate the gaze angle results of entry-level radiographer. Fig. 4 pertains to cases with abnormal findings, whereas Fig. 5 depicts cases without abnormal findings.

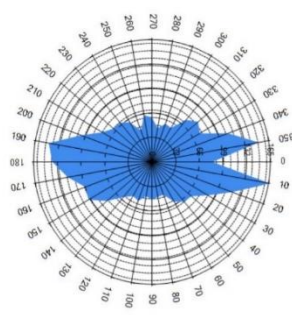


Figure 2: Angles of Gaze Movement In Experienced Radiographer (with Abnormal Findings)

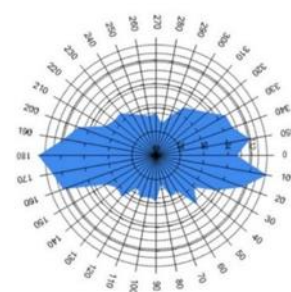


Figure 3: Angles of Gaze Movement In Experienced Radiographer (without Abnormal Findings)

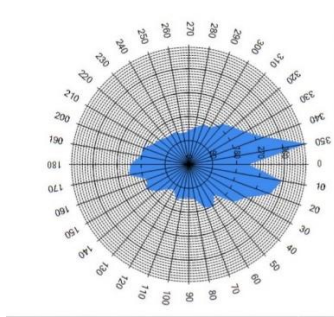


Figure 4: Angles of Gaze Movement In Entry-Level Radiographer (with abnormal findings)

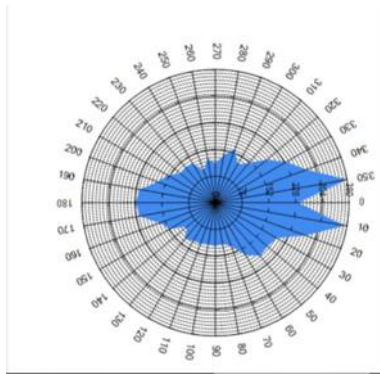


Figure 5: Angles of Gaze Movement In Entry-Level Radiographer (without Abnormal Findings)

A comparison between entry-level and experienced radiographers revealed notable differences in angles of gaze movement. In the graphs, the numbers displayed on the outer circumference represent the angles, while the numbers within the circumference, namely the radii, indicate the frequency of the corresponding angles. Skilled practitioners exhibited a higher frequency of gaze movement angles around 180 degrees within the 360-degree spectrum. This is demonstrated in Fig. 2 and Fig. 3, representing the results with and without abnormal findings, respectively. In Fig. 2, angles such as 10 degrees, 350 degrees, 190 degrees, and 180 degrees were observed with higher frequencies. Similarly, in Fig. 3, angles like 10 degrees, 180 degrees, and 350 degrees were more frequent. When examining the results for entry-level radiographer, as shown in Fig. 4 and Fig. 5 for interpretations with and without abnormal findings, respectively, angles such as 350 degrees and 10 degrees were more observed in their gaze movement. Comparing the results presented in Fig. 2 and Fig 4, or comparing the results presented in Fig. 3 and Fig. 5, it is evident that experienced radiographer frequently exhibit gaze movement angles near 180 degrees, a pattern not as pronounced in novice practitioners. This suggests that experienced radiographer tends to pause and carefully observe between fixation points when shifting their gaze, while entry-level radiographer appear to transition their gaze more promptly from one point to another.

6. Discussion

The paper highlighted differences in gaze movement between entry-level and experienced radiographers during interpretation. The analysis of angles of gaze movement, a hypothesis was formulated. The hypothesis suggests that skilled practitioners

pause for careful observation between fixation points when shifting their gaze, whereas novices shift their gaze more promptly from one point to another, lacking this intermediate pause. While not initially planned, based on the results of angles of gaze movement, average speeds of gaze movement were calculated using accumulated distance and time. The following Table 1 represents those results.

Average speeds(pixel/sec)	With abnormal findings	Without abnormal findings
Experienced radiographer	533.24	218.83
Entry-level radiographers	13966.75	2,893.05

Table 1: Average Speeds of Gaze Movement

It is evident that entry-level radiographer has faster average speeds of gaze movement compared to experienced radiographer. The accumulated distance of entry-level radiographer was longer than experienced radiographer. The distinction in accumulated distance and average speed suggests that entry-level radiographer tends to survey a wider area rapidly, whereas maintains experienced radiographer a deliberate focus on specific regions. Calculating average speeds of gaze movement further supported the hypothesis stated above.

Considering that entry-level radiographer possesses less experience than skilled practitioners, they might find it challenging to predict the location of anomalies. This could potentially explain why entry-level radiographers tend to survey the entire CT images thoroughly and quickly. In contrast, experienced radiographer can infer the approximate location of anomalies, allowing them to concentrate on specific areas. Interviews with experienced practitioners aligned with this explanation. Inexperienced individuals may have attempted to observe a broad area as much as possible. As a result, the gaze of entry-level radiographer may have exhibited movements along the Z-axis (the head-foot direction in CT images), while simultaneously surveying the XY plane comprehensively. Conversely, experienced radiographer tends to direct their gaze along the Z-axis (head-foot direction). Therefore, in a series of similar CT images, should an anomaly be detected, it could be recognized as a flicker. According to the previous research [9], the characteristics of human gaze encompass distinct roles for central vision and peripheral vision, where grasping stimuli occurs through peripheral vision and subsequently confirming details via central vision constitutes a fundamental process. Experienced radiographers shift their gaze along the Z-axis (head-foot direction) with peripheral vision, and subsequently enhance the resolution with their central vision when anomalies are detected. This phenomenon aligns with the description provided by adept physicians as "recognizing anomalies as flickers."

Based on physiological factors in previous research the reciprocal motion of gaze being predominantly horizontal and vertical rather than up and down has been frequently observed [10].

In this study, consistent with Fig. 2 through Fig. 5, reciprocal movements are frequently observed, and upon examining raw gaze data acquired from the device, it was found that horizontal reciprocal gaze movements are more prevalent than vertical ones.

Additionally, the gaze patterns of experienced radiographer revealed repeated back-and-forth movements along lines near 180 and 360 degrees. Similar repetitive movements along horizontal and vertical lines have been observed in previous studies [9]. The research has been elucidated that repetitive movements along horizontal lines are more frequent than those along vertical lines. In other previous research, it has revealed that the capability to accurately perceive information is higher in the horizontal direction of eye movements compared to the vertical direction [11]. This paper also found that entry-level radiographer exhibited more frequent back-and-forth movements along horizontal lines than vertical ones. This phenomenon can be attributed to reasons such as the relatively easier execution of horizontal movements compared to vertical ones, as well as the cautious tendency of entry-level radiographers due to the difficulty in anticipating the location of abnormal findings. Consequently, entry-level radiographers may opt to observe a broader scope of the CT image.

7. Conclusions

The purpose of this paper is to conduct a comparative analysis between entry-level and experienced radiographers regarding the angles of gaze trajectories, which could serve as the foundation for algorithms exploring findings in artificial intelligence (AI). Furthermore, the objective is to propose recommendations for AI to learn from the disparities in gaze trajectories between entry-level and experienced radiographers, ultimately enabling more accurate and effective image diagnostics in the future. This paper specifically analyzed the angles of gaze movement and speed of entry-level and experienced radiographers. However, it is important to note that this research had limitations in terms of a limited number of participants and sample size. Future studies should involve a larger sample size to further investigate the elements of algorithms during radiological interpretation.

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