Influence of Experience and Training on Dental Students' Examination Performance Regarding Panoramic Images

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Abstract: Physician training has greatly benefitted from insights gained in understanding the manner in which experts search medical images for abnormalities. The aims of this study were to compare the search patterns of 30 fourth-year dental students and 15 certified oral and maxillofacial radiologists (OMRs) over panoramic images and to determine the most robust variables for future studies involving image visualization. Eye tracking was used to capture the eye movement patterns of both subject groups when examining 20 panoramic images classified as normal or abnormal. Abnormal images were further subclassified as having an obvious, intermediate, or subtle abnormality. The images were presented in random order to each participant, and data were collected on duration of the participants' observations and total distance tracked, time to first eye fixation, and total duration and numbers of fixations on and off the area of interest (AOI). The results showed that the OMRs covered greater distances than the dental students ($p<0.001$) for normal images. For images of pathosis, the OMRs required less total time ($p<0.001$), made fewer eye fixations ($p<0.01$) with fewer saccades ($p<0.001$) than the students, and required less time before making the first fixation on the AOI ($p<0.01$). Furthermore, the OMRs covered less distance ($p<0.001$) than the dental students for obvious pathoses. For investigations of images of pathosis, time to first fixation is a robust parameter in predicting ability. For images with different levels of subtlety of pathoses, the number of fixations, total time spent, and numbers of revisits are important parameters to analyze when comparing observer groups with different levels of experience.

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Keywords: dental education, oral radiology, oral and maxillofacial radiology, radiographs, diagnostic reasoning, eye-tracking, educational measurement

Submitted for publication 3/19/15; accepted 6/8/15

According to the Merriam-Webster dictionary, image interpretation is defined as the "act or results of explaining something." Although this definition is not specific for radiologic interpretation, it does describe the process radiologists use daily: putting into clear and articulate thoughts their observations and then deriving diagnostic meaning from them.

Baghdady et al. recently proposed two approaches to image interpretation in oral and maxillofacial radiology.[1-3] The first approach is a systematic or analytic strategy, sometimes referred to as "forward reasoning." This strategy, also described by White and Pharoah,[4] directs dental students to identify and analyze the radiologic features of an abnormality in a step-by-step manner (location, size and shape, borders, internal structure, and effects on the surrounding structures), associate the features with a category of disease, and make an interpretation based on these findings. Baghdady et al. suggested that the link made between the underlying disease process and the identified feature must come from a strong understanding of the basic science—in other words, the pathophysiology of disease development.[1] This analytic strategy has been used to teach dental students how to interpret images and to avoid bias and drawing premature conclusions before the close of the analytic process. As mentioned by Ambrose et al., this evolutionary process starts with the student's prior knowledge; but to master the action, the student must acquire new skills and practice them.[5] At the same time, students must be able to self-assess their strategies and modify them if needed in order to evolve as a practitioner.

A second strategy, the non-analytic or "backward reasoning" strategy, is an approach predominantly used by expert radiologists.[1-3] This strategy views the abnormality as a whole rather than in its individual radiographic feature parts and leads to a provisional interpretation. This approach is often considered to be done automatically and without conscious awareness.[6] After the provisional interpretation is made, the radiologist undertakes a search for radiographic features that support this provisional interpretation. The process is repeated until a more definitive interpretation can be made.

This study addresses the first step in the interpretation process: identification or localization of an abnormality. Panoramic imaging is a commonly used imaging technique that produces a complex two-dimensional representation of three-dimensional anatomy. This seemingly simple but important concept can make image interpretation difficult for dental students. An interpretation method that is currently taught for panoramic images is the "region-by-region" systematic approach described by White and Pharoah.[4] This strategy divides a panoramic image into a number of discrete but overlapping regions: mandible, midface, soft tissues, superimpositions and ghost images, and, finally, the dentition. This method directs the untrained eyes of dental students to review specific regions and imaging features of the panoramic image.

No study has evaluated if experienced clinicians search panoramic images in a systematic way or if they use a free search pattern, which may be less time-consuming and economical. Recently, eye tracking has been used in a variety of fields in medicine for physical examination and the investigation of electrocardiograms, radiologic, and histopathologic images. Contemporary eye tracking devices use pupil center corneal reflection. This method focuses an infrared beam on the cornea and pupil, producing reflections that can be captured by a camera. Eye tracking studies use a number of metrics to describe the movements of the eyes. For example, a "fixation" is "the act or an instance of focusing the eyes upon an object" (Merriam-Webster dictionary)—that is, the length of time the eye remains on a single location. A "saccade" is a "small rapid jerky movement of the eye, especially as it jumps from fixation on one point to another" (Merriam-Webster dictionary). In other words, it is the path of eye movement made by an observer between each fixation. Blinking, a more familiar term, is "to close and then open your eyes very quickly" (Merriam-Webster dictionary).

Eye tracking studies utilizing posterior-anterior chest images, brain computed tomographic images, and mammograms have demonstrated that experienced radiologists view images differently from medical students or resident radiologists. Manning et al. found that experts spent less time on each image, had fewer fixations with longer saccades, and covered less distance than novices.[7] Matsumoto et al. concluded that experienced radiologists not only identified the region of abnormality but examined other structures they knew could host disease.[8] In contrast, less important structures (those the experts knew could not host disease) were passed over rapidly. This method of pattern recognition is a normal evolution for experts, allowing them to assess the image as a whole and with fewer eye movements. Krupinski and Kundel et al. found that radiologists required nearly half the time to identify an abnormality compared to radiology residents, but they also required more time to make true positive and false positive diagnoses and less time for a true negative diagnosis.[9,10] These authors as well as others have concluded that, as expertise in this skill is developed, efficiency and economy of effort are gained.[8-12]

In dentistry, only Suwa et al. have examined eye movement patterns of clinicians over a single axial image from a larger multidetector CT image set of the head and neck; they found that all subjects spent more time and made longer and greater numbers of fixations on the normal images.[13] These researchers concluded that the differences they observed between normal and abnormal CT images (images were of ameloblastoma, a large benign tumor causing expansion) could be explained on the basis that participants used a forward reasoning approach for normal CT images and a backward reasoning method for CT images with pathology.

The aim of this study was to analyze panoramic image search strategies in dental students and certified oral and maxillofacial radiologists. Since panoramic images are used commonly in dentistry, it is vital that students learn to competently view these images, differentiate normal from abnormal, and make interpretations so that patient care is optimized. Understanding the experienced practitioners' search patterns and methods of image interpretation may enable us to modify our approach in teaching dental students. It also contributes to the body of knowledge that clinical reasoning is along a spectrum of development from novice to expert. We hypothesized that the oral and maxillofacial radiologists would spend less time, have fewer fixations, blinks, and saccades, and cover less distance on the panoramic images than the dental students. We also hypothesized that they would locate the area of interest (AOI) faster, spend less time viewing it, and have fewer fixations and revisits.

Materials and Methods

Research ethics approval was obtained for the study from the University of Toronto Health Sciences Research Ethics Board (Protocol 28709). Fourth-year dental students were recruited from the Faculty of Dentistry of the University of Toronto. This group was selected because they had received training on panoramic image interpretation and had some experience reporting these images. The experienced practitioners group consisted of certified oral and maxillofacial radiologists (OMRs) who were either Diplomates of the American Board of Oral and Maxillofacial Radiology or Fellows of the Royal College of Dentists of Canada in Oral and Maxillofacial Radiology. Without any previous data relating to this specific area of research, a power analysis could not be reliably made. We therefore used previous publications,[7,8,9,11] relatively similar to ours, to estimate our sample size at 20 per group. Ultimately, 30 dental students and 15 experienced practitioners were recruited. **[Dr. Turgeon: can you add a couple of sentences about how both groups were recruited and selected?]**

Approximately 120 digital panoramic images were selected and anonymized from patient files in the Faculty of Dentistry at the University of Toronto and from the Department of Dental Oncology at Princess Margaret Hospital, Toronto. Of these, 20 images were ultimately selected, five of which were normal (a panoramic image was considered normal if it was free of bony pathoses, identifiable dental caries, severe periodontal disease, or image production artifacts). The remaining 15 images contained one or more regions of pathosis, and these were subclassified further based on their perceived difficulty in detecting (not diagnosing) the abnormality. These images were reviewed by an expert panel consisting of three certified OMRs. A conventional Delphi panel method was used in which 100% agreement among all three experts was required to accept an image.[14] A summary of the diagnoses along with the number of pathoses per image is shown in Table 1.

The RED-m (Sensomotoric Instruments, Teltow, Germany) system was used to track the eye movements of the participants. The operating distance between the device and an observer's eyes was between 50 cm and 75 cm, with 60 cm to 65 cm being the best position. The system has a gaze position accuracy of 0.5° and a spatial resolution of 0.1°. At 65 cm, a 0.5° change corresponds to approximately

Table 1. Identification and classification of fifteen abnormal images

Category	Diagnosis	Localization	Number of Pathoses
Obvious	Gingival fibromatosis	Right mandible	1
	Complex odontoma	Right mandible	1
	Keratocystic odontogenic tumors	Left maxilla, left mandible (x2), right mandible	4
	Supernumerary teeth	Right and left maxilla, left mandible	3
	Sialolith	Left soft tissue	1
Intermediate	Buccal bifurcation cyst	Left mandible	1
	Supernumerary tooth	Left maxilla	1
	Metastatic lesion	Left mandible	1
	Stafne bone defect	Right mandible	1
	Benign tumor/cyst	Right maxilla	1
Subtle	Benign tumor/cyst	Anterior mandible	1
	Carcinoma	Left maxilla	1
	Lymphoma	Right maxilla	1
	Odontogenic myxoma	Right maxilla	1
	Metastatic lesion	Left maxilla	1

5 mm. The eye tracker was mounted at the base of the screen of a 15.6-inch laptop computer (Latitude E6530, Dell Corporation, Round Rock, TX, USA) with a display resolution of 1600 by 900 pixels. A second screen was used by the principal investigator (DPT) to ensure subjects stayed within the tracking range and operating distance of the system. A nine-point initial on-screen calibration was used for each participant and was followed by a four-point calibration to confirm the preliminary calibration. We used the calibration criteria of Matsumoto et al.[8] This group considered the calibration as being successful if the maximum spatial error is $<1°$ and the average $<0.5°$.

Participants were told to look at the images as if they were in their offices. They were also told that there would be no time limit, but to assume there was a patient in the chair waiting for them. Finally, participants were told that some images could contain none, single, or multiple areas of pathosis. The 20 panoramic images were shown to each subject in random order. The data for each subject were exported from BeGaze (Sensomotoric Instruments, Teltow, Germany) into Excel (Microsoft Corp., Redmond, WA, USA), where they were grouped according to participant type (dental students or OMR), whether the image was normal or abnormal, and level of difficulty localizing the abnormality (obvious, intermediate, subtle). All the images were shown using software in which no manipulation of the contrast, brightness, and magnification was possible. To compensate for this, the images were all pre-processed by the principal investigator for contrast and brightness.

A mixed effect analysis of variance (ANOVA) that included group (dental students vs. OMRs) as the between-subjects variable and type of image (normal, obvious, intermediate, or subtle) as the within-subjects variable was performed using SPSS (IBM Corp., Endicott, NY, USA). Given the number of comparisons in these analyses (ten parameters evaluated), we used the Bonferroni correction and set the alpha level at $p<0.005$. We used the Tukey-Kramer post hoc test and set the alpha level at $p<0.05$.

Results

Comparison of Normal Images and Images of Pathoses

All the participants utilized longer search times for normal images than abnormal ones ($F(3,129)=10.27$, $p<0.001$), regardless of the degree of subtlety of the abnormality: obvious ($p<0.001$), intermediate ($p=0.002$), and subtle ($p=0.03$) (Table 2). There were, however, no differences between the search times of the images based on degree of subtlety ($F(1,43)=3.405$, $p=0.072$). The experts (OMRs) spent more time searching the normal images than the abnormal ones ($F(3,129)=8.217$, $p<0.001$), but this was not the case for the dental students where no such differences were found.

All the participants accrued a greater number of eye fixations on normal images than images of pathoses ($F(3,129)=12.365$, $p<0.001$), and there were no significant differences between the dental students and OMRs ($F(1,43)=2.423$, $p=0.127$). The OMRs made more eye fixations on normal images than abnormal images, but this was not the case for the dental students where no such differences were seen.

All the subjects covered greater distances across the image for normal images compared with images of pathoses ($F(3,129)=13.45$, $p<0.001$). Post hoc testing revealed this to be the case regardless of the level of subtlety. No differences were found between the dental students and OMRs ($F(1,43)=0.151$, $p=0.699$). The OMRs covered more distance on normal images than the dental students but less distance on images of obvious pathosis. No significant differences were found between the dental students and OMRs with respect to the number of blinks that occurred when investigating an image, be it normal or one of pathosis.

All the participants utilized a greater number of saccades on the normal images than the images of pathosis ($F(3,129)=11.951$, $p<0.001$), regardless of the degree of subtlety of the pathosis. As well, the OMRs utilized a greater number of saccades than did the dental students for normal images but fewer saccades for images of pathosis ($F(3,129)=8.255$, $p<0.001$). No significant differences were found between the dental students and the OMRs for saccade length for both normal images and images of pathosis. Figure 1 provides a representative comparison in the search pattern between the dental students and the OMRs on a normal image, especially in terms of fixations and saccades.

Comparison of Images with Different Degrees of Subtlety of Pathoses

With regard to the detection of pathoses, the OMRs spent less time (7.4±1.4 seconds) than the

Table 2. Results for each parameter, image type, and participant (mean±SD)

Parameter Evaluated	Radiograph Classification	Dental Students	Oral and Maxillofacial Radiologists
Total time(s)	Normal	64.3±5.5	63.8±7.8
	Obvious	63.3±4.8	37.7±6.7
	Intermediate	62.7±4.6	45.7±6.6
	Subtle	61.7±4.9	45.8±6.9
Number of fixations	Normal	178±16	187±23
	Obvious	173±14	108±20
	Intermediate	171±13	128±18
	Subtle	173±14	130±20
Distance covered (cm)	Normal	702±73	904±103
	Obvious	709±61	526±87
	Intermediate	704±57	623±80
	Subtle	708±59	612±84
Number of blinks	Normal	20±3	12±5
	Obvious	23±3	10±5
	Intermediate	44±19	11±27
	Subtle	20±3	9±4
Number of saccades	Normal	187±16	191±23
	Obvious	181±14	112±20
	Intermediate	180±14	132±19
	Subtle	181±14	134±20
Length of saccades (ms)	Normal	26±2	28±2
	Obvious	26±1	31±2
	Intermediate	26±2	34±3
	Subtle	25±1	31±2
Time before 1st fixation(s)	Obvious	11.6±1.2	7.1±1.7
	Intermediate	15.4±1.7	8.7±2.5
	Subtle	10.9±0.8	6.5±1.2
Number of fixations in area of interest	Obvious	15±1	9±2
	Intermediate	13±2	18±3
	Subtle	15±2	18±3
Total time in area of interest	Obvious	5.7±0.5	3.2±0.7
	Intermediate	5.4±0.8	6.9±1.1
	Subtle	5.5±0.7	6.7±1.0
Number of revisits	Obvious	8±1	5±1
	Intermediate	7±1	7±1
	Subtle	7±1	8±1

dental students (12.6±1.0 seconds) before identifying an area of pathosis (F(1,43)=9.137, p=0.004), although we did not find a significant difference between the subtlety of the pathosis (F(3,86)=3.906, p=0.024). Significant differences were found between the degree of subtlety of pathosis and the number of fixations on the images (F(3,86)=5.799, p=0.004). Specifically, fewer numbers of fixations were required for images of obvious pathoses compared to those with subtle pathoses (p=0.01). The OMRs accrued fewer numbers of fixations on obvious AOIs compared to the dental students and to intermediate and subtle AOIs.

We found a significant main effect of image subtlety (F(3,86)=6.862, p=0.002) although there were no differences between the dental students and the OMRs (F(1, 43)=0.004, p=0.951). Post hoc testing revealed that less time was spent viewing an obvious AOI compared to intermediate (p=0.007) and subtle (p=0.02) AOIs and that the OMRs spent less time viewing obvious AOIs compared to students and intermediate and subtle AOIs.

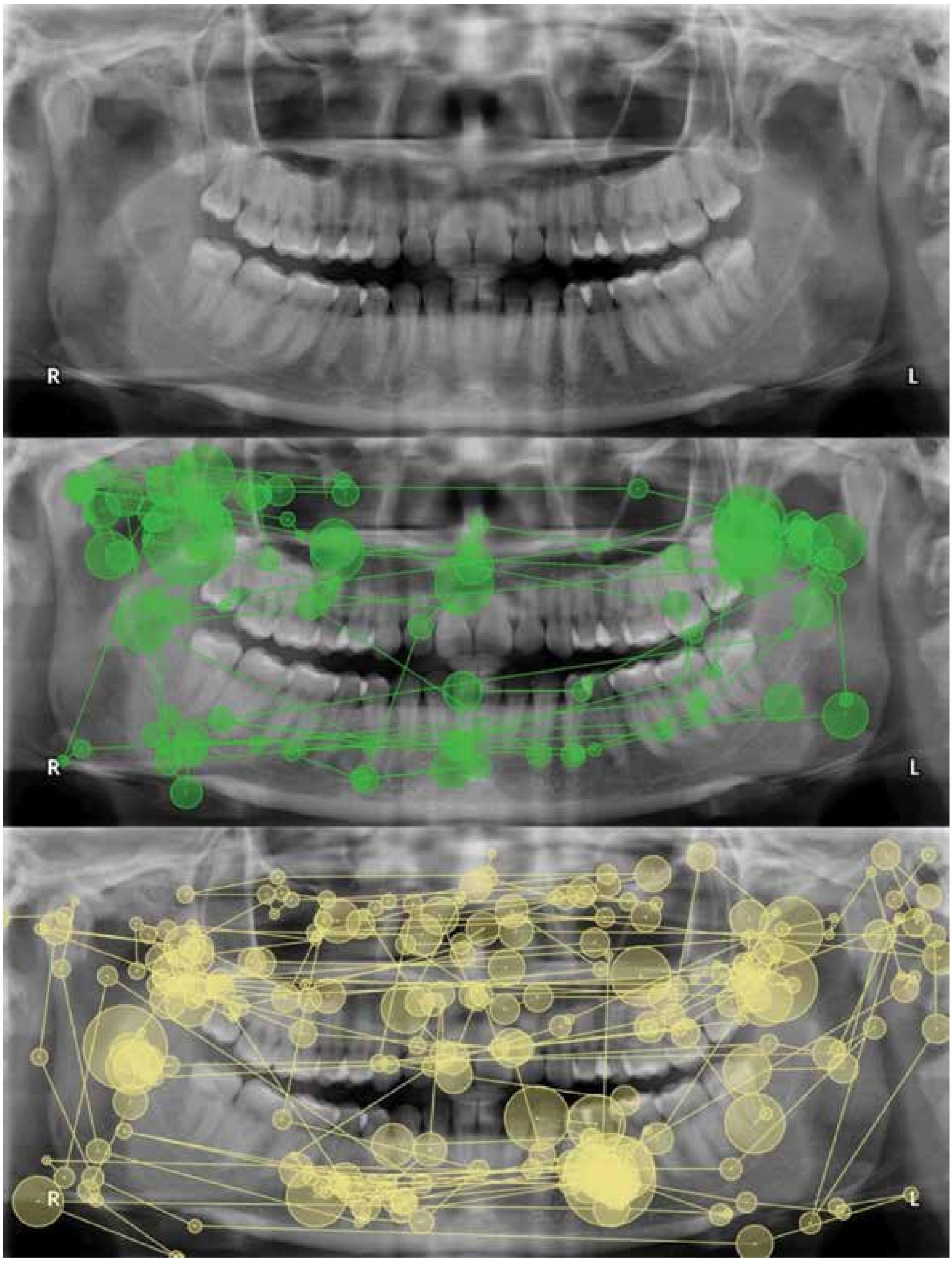

Figure 1. Normal panoramic image (top): comparison between a dental student's (middle) and an oral and maxillofacial radiologist's (bottom) scan path

Note: Fixations are represented by circles, with larger circles representing longer fixations and smaller circles shorter fixations. Saccades are represented by lines.

We found a significant interaction between the subtlety of the pathosis and observer groups (F(3,86)=5.592, p=0.005). Post hoc analysis showed that the OMRs made fewer revisits compared to the students on obvious AOIs. Figure 2 provides a representative comparison in the search pattern between the students and the OMRs on an abnormal image. It shows an increased number of fixations and saccades for dental students compared to OMRs.

Discussion

Radiologic interpretation relies on an ability to localize an abnormality, visualize a series of imaging features, and "make sense" of these features in light of other clinical information that may be available. Previously, we have investigated the image interpretation skills of dental students using a number of different pedagogical approaches, including forward and backward reasoning, but always attempting to link the basic sciences underpinning a radiologic feature with the interpretation.[1-3] These studies have, however, suffered from the limitation that we were never able to objectively confirm that a particular imaging feature was actually visualized by the subject. The present study represents the next evolution of our work and investigates our initial experiences with eye tracking in oral and maxillofacial radiology. Until now, only one study by Suwa et al. had investigated the eye movement patterns of dental clinicians investigating images, although that study was performed on single images from a multidector CT volume.[13] As CT images are not a "first line" imaging modality in predoctoral dental education, we decided to design this study around the interpretation of panoramic images.

Localization or identification of an abnormality relies on knowledge of the normal anatomy contained on an image and the range of what is considered normal. So that nothing is missed, textbooks on image interpretation often encourage a standardized search approach or pattern for each image, whether that image contains an abnormality or not. As we have demonstrated in this study, fourth-year dental students have only partially acquired these skills. Our results show that, for normal images, there were no differences in total time, number of fixations, distance covered, number of blinks, and number and length of saccades between the dental students and the OMRs. It was, however, interesting to note that although the total time spent searching a normal image was the same for the two subject groups, the OMRs were able to cover, on average, approximately 200 more centimeters of distance across the image than the dental students. As well, the OMRs were less likely to be distracted by areas of the image known not to harbor pathoses whereas the dental students did not recognize this. This difference has also been seen in studies involving medical images.[7,8]

Significant differences were noted between the dental students and OMRs when investigating images of pathosis. The OMRs spent less total time and covered less distance before identifying an area of pathosis, had fewer numbers of fixations, and had fewer saccades than the dental students. These metrics may therefore be the most robust in future studies of clinician expertise level and pathosis identification. These variables suggest that OMRs are capable of quickly differentiating between something that is normal and something that is not and are less distracted by irrelevant visual data. This finding is consistent with the study by Dreiseitl et al., who found that experienced dermatologists could visualize a pigmented lesion faster than those with less experience and training.[11] Furthermore, the OMRs demonstrated a higher level of focus compared with the students as evidenced by fewer blinks and longer saccades. This latter metric implies that OMRs are able to sample visual information on a wider scale than students. Taken together, these parameters demonstrate the greater visual efficiency of the OMRs as a group compared to the dental students.

With respect to the interpretation of pathoses of different levels of subtlety, no differences were found between the dental students and OMRs for those pathoses classified as intermediate or subtle. This finding is consistent with the conclusion by Matsumoto et al. who noted that experts searched more inconspicuous but more clinically relevant regions than their novice counterparts and implies that stratification of difficulty may not be necessary in future studies.[8] For more subtle pathoses, the OMRs may have had to shift their search strategy from one that was "backward reasoning" to one that was "forward reasoning." No such differences were seen with the dental students, who may not have the experience to change their approach.

[Dr. Turgeon: please add a few sentences on limitations of the study and directions for future research]

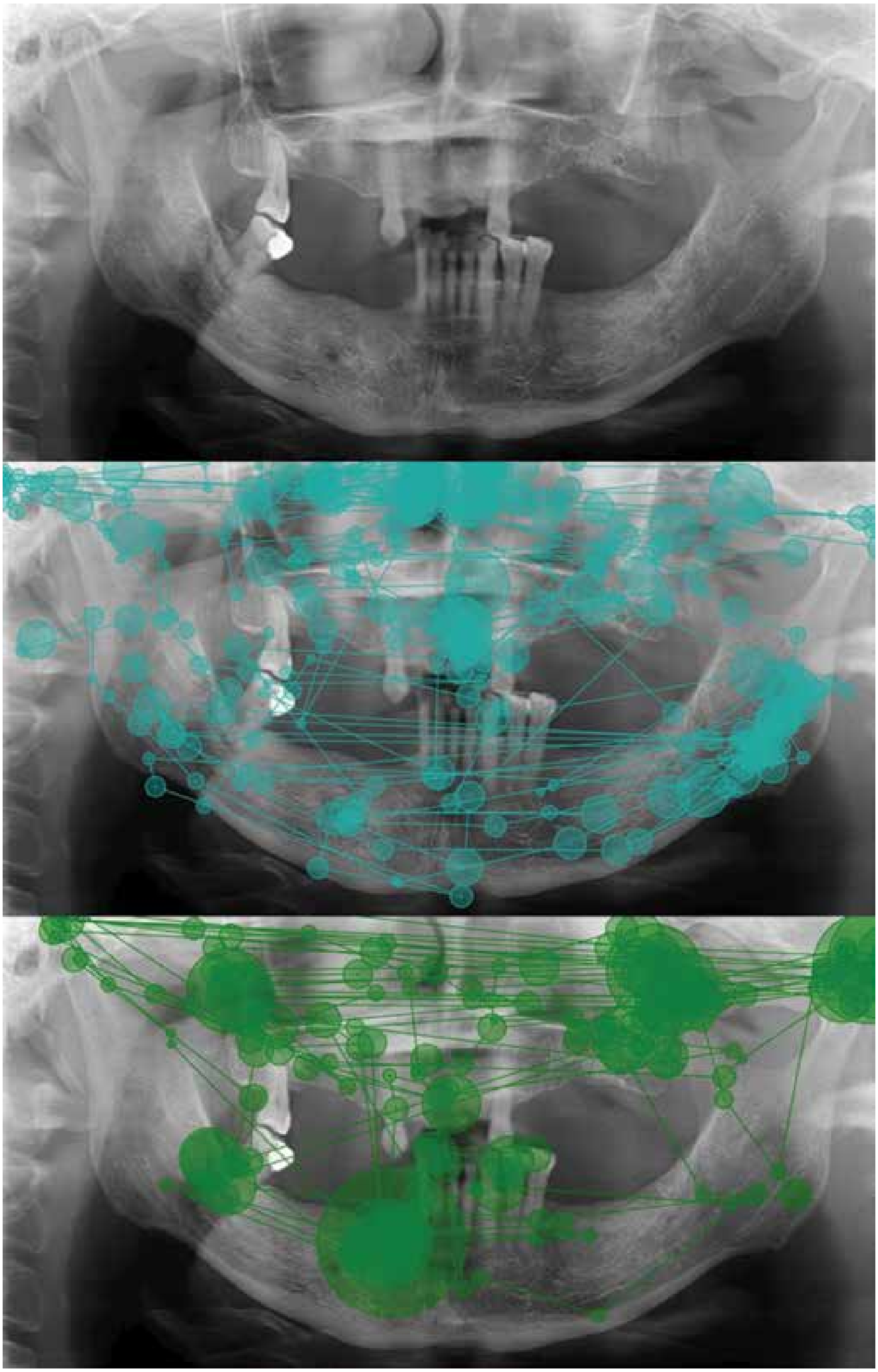

Figure 2. Abnormal (subtle) panoramic image of a malignancy located at the posterior border of the left maxilla (top): comparison between a dental student's (middle) and an oral and maxillofacial radiologist's (bottom) scan path

Conclusion

This study identified key parameters in eye tracking that may be useful for future research that we, and potentially others, may conduct. For example, we found that apart from the distance covered by the eyes of the dental students and OMRs, other parameters such as total time spent, number of fixations, number of blinks, and number and duration of saccades were not useful discriminators. In investigations of images of pathoses, time to the first fixation on a region of pathosis is an important parameter. If observers are challenged with different levels of subtlety of pathoses, the number of fixations, total time spent, and number of revisits to a region of interest (particularly for obvious pathoses) are important parameters to analyze when comparing observer groups with different levels of experience. Depending on the type and objectives of future studies, these parameters may be the most useful upon which to concentrate analyses.

Acknowledgments

The authors would like to thank Drs. Michael Pharoah and Susanne Perschbacher for their help in selecting the images and Dr. Ryan Brydges for his help with the statistical analysis.

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