The Effect of Processing and Learning Approaches on Diagnostic Accuracy in Novice Clinicians

by

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Faculty of Dentistry
University of Toronto

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Abstract

**Background:** Different approaches to processing (analytic and non-analytic) and learning (basic science and structured algorithm) may be used by novice clinicians in diagnostic oral radiology. However, little is known about how their interaction might impact diagnostic accuracy.

**Objectives:** The objectives of this study were to: 1) evaluate the interaction between processing and learning approaches on the diagnostic accuracy of novice clinicians; and 2) evaluate the effect of processing approaches on the diagnostic accuracy of experienced clinicians. **Methods:** In this computer-based study, participants interpreted 32 radiographic images divided into two sections with different testing instructions; one that favoured analytic and the other non-analytic processing. **Results and Conclusions:** This study demonstrated that diagnostic errors made by novice clinicians were not associated with non-analytic processing. The study further suggests an interaction between learning approach and order of testing instructions. For the experienced clinicians, testing instructions did not impact on their diagnostic accuracy suggesting that they used a combined processing approach.
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Chapter 1

1.1 Introduction

In dentistry, oral radiology plays an important role in diagnosis and treatment.¹ The undergraduate dental curriculum includes lectures and demonstrations on radiographic technique, radiation safety, normal radiographic anatomy and pathoses of the jaws. Dental students need to acquire sufficient knowledge of the radiographic interpretation of intra- and extra-oral projections. The teaching emphasis of the interpretation process is the identification and visualization of characteristic diagnostic features of disease. Following this search for features, students are taught to use an analytic processing strategy in which they are instructed to analyze and make sense of the radiographic features in order to arrive at an interpretation.² There is evidence from studies in dermatology, another field which requires visual cues, which suggest that this type of analytic processing, focusing on the identification and interpretation of diagnostic features, may result in decreased diagnostic performance.³ As well, the same radiographic features can be taught to students using different methods (learning approach). Previous research in oral radiology has shown that understanding the disease mechanism underlying the radiographic feature (integrated basic science learning) provides to novice clinicians a coherent framework which can potentially improve their diagnostic accuracy when compared with structured algorithm learning.⁴ In structured algorithm learning, the features are organized in subcategories describing localization of the abnormality and assessment of the periphery, shape, internal structure and effect of the entity on the surrounding structures. However, little is known about the interaction between processing (analytic vs. non-analytic) and learning approach (basic science and structured algorithm) on students’ diagnostic accuracy in oral radiology. If integrated basic science learning would facilitate non-analytic processing, then more emphasis should be placed on non-analytic processing strategies during the interpretation process.

1.2 Processing Approaches

Undergraduate dental students may interpret a radiograph using either analytic or non-analytic processing. Using analytic processing, the student identifies all the radiographic features of a particular abnormality seen on an image, analyzes them, and then arrives at an interpretation.
Using non-analytic processing, the student arrives at an interpretation after looking at the image as a whole and then chooses a diagnosis that ‘‘makes sense’’ based on an initial diagnostic hypothesis. Selecting an interpretation on the basis of an unconscious comparison of the whole image to a pattern previously encountered on another similarly-appearing radiographic image would also be consistent with non-analytic processing.\(^5\)

### 1.3 Learning Approaches

The same radiographic features can be presented to the students using different methods, referred to as learning approaches. The learning approaches (basic science and structured algorithm) might influence the processing approaches used during the interpretation process (analytic and non-analytic processing) and the diagnostic accuracy of the clinician.

Analytic processing can be encouraged through training the student to memorize lists of presenting features or by presenting the same features in a structured algorithm during their initial introduction to the interpretation process. White and Pharoah, in their book *Oral Radiology: Principles and Interpretation*, describe a five-step analytic approach to radiographic interpretation. The analysis includes localization of the abnormality and assessment of the periphery, shape, internal structure and effect of the entity on the surrounding structures. The radiographic interpretation is then based on the different features that the observer sees during this structured analysis of the image.\(^2\)

Several studies have demonstrated the positive role of teaching the students the underlying pathogenesis (i.e. the ‘‘basic science’’) behind the abnormality. The knowledge of the basic science underpinning the disease process can favor non-analytic processing and improve diagnostic accuracy of novice clinicians. Instead of relying on rote memorization of the different features of each disease, knowledge of the physiopathology behind the abnormality can help the student to understand the constellation of features as a whole and select the most appropriate interpretation.\(^4,6\) Woods *et al.* (2007b) suggested that sound knowledge of basic sciences, specifically the causal explanations for disease signs and symptoms, helps novice clinicians learn to diagnose disease and maintain their diagnostic accuracy over time. Woods argues that understanding the basic science underpinnings of an abnormality can provide causal connections between the different clinical features of a specific disease, and allow the novice clinicians to arrive at a diagnosis that makes sense to them.\(^7\) Baghdady *et al.* (2009) demonstrated the value...
of this basic science approach in oral radiology. In their study, undergraduate dental and dental hygiene students were taught four potentially confusing radiographic abnormalities. Participants were randomly divided into three learning conditions. The basic science group was taught explanations of the physiopathology underlying the abnormalities. The structured algorithm group was taught the radiographic features of the abnormalities but without an explanation as to why they appeared. Finally, the feature list group was taught the four diseases using an unstructured list of radiographic features. Students who were taught using the basic science approach had higher diagnostic accuracy than students who were taught using the structured algorithm or feature list approaches. The study suggested that a basic science approach provided the novice clinicians with a coherent mental representation of each disease and their radiographic features, referred to as “conceptual coherence”. This allowed the student to choose the diagnosis that “made sense” based on the underlying pathophysiologic mechanism. Rather than relying on the rote memorization of the radiographic features, the student understand why the features are present and why they occur simultaneously. 

1.4 The Value of Basic Science Knowledge

Several mechanisms for the use of basic science knowledge have been explored, although a definitive explanation remains to be found. The knowledge of the basic science underpinning the disease process was shown to increase diagnostic accuracy with novice clinicians. However, earlier studies have failed to demonstrate how experts use basic science knowledge while diagnosing a case. In the Boshuizen and Schmidt (1992) study, experts were not using the basic science knowledge extensively when they were instructed to diagnose a case using a “think-aloud” protocol. A subsequent study (1993) evaluated the effect of expertise and time allotted to examine a case and clinicians’ level of expertise of their pathophysiologic description underlying the case presented. When novice clinicians were given less time to study a case, they usually produced shorter pathophysiological explanations, suggesting that under a time constraint, less pathophysiologic knowledge was activated. With experienced clinicians, shorter explanations were given and this was independent of the amount of time provided to review a case. Boshuizen and Schmidt (1992) attributed the results to knowledge encapsulation; “elaborate knowledge of the world that becomes ‘chunked’ into a limited number of highly inclusive concepts that have the same explanatory power as the original elaborate structure”. With experience, clinicians’ knowledge is thought to be organized into “more global and comprehensive concepts than
subjects of lower levels of expertise”. This qualitative shift enables the clinicians to process the information faster and in a more coherent manner.9

In a series of experiments, Woods and colleagues investigated the development of conceptual coherence and the value of basic science in a variety of domains. Undergraduate psychology students were taught four “pseudo-endocrinology” diseases using either a basic science explanation or a feature list. The pseudo-endocrinology diseases included in the study were artificial disorders created using a list of 24 signs and symptoms from four endocrine disorders (hypothyroidism, hyperthyroidism, Addison’s disease and Cushing’s disease). The first part of the study focused on the recognition of encapsulated knowledge, which is defined by Schmidt and Boshuizen (1993) as the acquired basic science knowledge that becomes integrated within the clinical knowledge.9 Each participant underwent a learning phase followed by a diagnostic test. The students in the basic science group recognized significantly more words or phrases describing the encapsulated knowledge than the students in the feature list group. The second part of the study focused on the response time of the students. The students in each learning condition were randomly divided into two groups. One group was instructed to go through the diagnostic test as fast as they could, which theoretically favours non-analytic reasoning, while the second group was instructed to focus on the accuracy of the diagnosis, which favours analytic reasoning. The performance of students who were taught using a feature list approach dropped from 73% to 66%, when instructed to diagnose as fast as they could. However, the performance of students who were taught using a basic science approach improved slightly from 67% to 71% when instructed to complete the diagnostic test as quickly as possible. Although small, these differences were significant. These results were attributed to the students developing a more coherent representation of the diseases and the clinical features associated with them when they understood the basic science underpinnings each disease. This approach allowed participants to access the information learned more rapidly and easily than the students who learned with a feature list. Instead of processing the features individually and slowly, the features were dealt in a more coherent manner. However, instruction to focus on the accuracy might have disrupted this coherence, resulting in decreased diagnostic accuracy. As well, students taught the feature list might be processing the features individually and this might explain why their diagnostic accuracy improved when instructed to focus on the accuracy of the diagnosis and decreased when instructed to diagnose as fast as they could. This work also demonstrated experimentally
that understanding the underlying disease mechanism could lead novices to successfully use a non-analytic process of clinical reasoning and, instructions to favor analytic processing might result in decreased diagnostic accuracy.10

1.5 Speed-Focused Testing Condition

The type of processing (analytic vs. non-analytic) used during radiographic interpretation may be not only influenced by the leaning approaches (basic science and structured algorithm), but might also be influenced by the instructions given to the students during the test (testing conditions). Instructions to focus on the speed of the interpretation have been used to control the attentional demand of participants to a task, and to elicit analytic or non-analytic processing. Speed-focusing has been used in order to favour a non-analytic process, and accuracy-focusing has been used to favour a step-by-step analytic process. Norman et al. (1989) evaluated the effect of a speed-focused testing condition on diagnostic accuracy and the response times of individuals at five different levels of expertise in dermatology. In this study, accuracy in expert clinicians was associated with short response times, and erroneous diagnoses were associated with a significantly longer response times. Norman and colleagues suggested that a non-analytic, automatic “pattern-recognition” process was associated with correct diagnoses, and that an analytic “feature-by-feature” process was associated with incorrect diagnoses due to a failure of pattern recognition. This study also demonstrated that expert clinicians performed better than novice clinicians, since as errors decreased with expertise. However, even if the error rate decreased with expertise, a constant proportion of errors was still committed on slides that were judged to be typical by colleagues. The presence or absence of specific diagnostic features of a disease was not a good predictor of expert diagnostic accuracy. The authors suggested that the results of the study were consistent with a model of expertise in which similarity to previously encountered cases facilitates the diagnosis. So while expertise was accompanied by fast pattern recognition, potential confusion with previous similar examples could result in erroneous diagnosis.11 Barrows et al. suggested that the initial diagnosis made by a clinician could influence a decision regarding the presence or the absence of certain features. For example, the clinician’s first impression of a clinical problem may bias the person to identify certain features and miss other features in order to match the initial diagnosis.12 These conclusions are consistent with a non-analytic reasoning process in experts where the presence of specific features is not a
good predictor of expert performance. Instead, experts engage in a rapid pattern recognition process.

1.6 Feature Identification in Oral Radiology

In radiology, work by Lesgold et al. using chest radiographs has provided some insight into how radiologists and residents use different features. Their work showed that with expertise, the features identified by clinicians are more specific to a case and that the perception of the different feature usually takes into account more peripheral factors. Their results demonstrate that experts are doing “more inferential thinking and ending up with a more coherent model of the patient shown in the film”. Experts were better able to discriminate irrelevant features using their technical knowledge of image acquisition and more evolved features perception. The authors also found an association between the diagnostic accuracy of residents and expert radiologists on chest radiographs, and their analytic processing of biomedical knowledge. Thus, the knowledge of the underlying basic science mechanism may enable experienced clinicians to have a more coherent mental representation of the disease shown on the radiographic image resulting in higher diagnostic accuracy.\(^{13}\) Other studies in radiology focused on the perception of the abnormality. Oestmann et al. looked at the correlation between the viewing time and detection of both subtle and obvious lung cancer. With increasing viewing time, there was an incremental increase of detection of both subtle and obvious cancers. This increase was especially pronounced during short viewing times of 4 seconds or less while the increase between 4 seconds and unlimited viewing time was very small. With unlimited viewing time, 24% of subtle cancers and 2% of obvious cancers were still not detected.\(^{14}\) Although this study looked at the detection of the abnormality and not the interpretation, the result support the concept that a fast, non-analytic processing approach may be used by experienced clinicians to detect an abnormality. It also supports a previous study which has shown that “significant information can be extracted from flash viewing” of an image.\(^{15}\)

1.7 Feature Identification in Other Domains

Studies in other domains have also looked at factors influencing the identification of diagnostic features by clinicians. Hatala et al. evaluated the association between clinical history, feature identification and diagnostic accuracy on electrocardiograms. In their study, cardiologists, medical residents and medical students were given a biased (incorrect) or a non-biased (correct)
clinical history. They were then instructed to identify features present on an electrocardiogram or to give their interpretation. Participants had higher diagnostic accuracy if the electrocardiogram was accompanied by a non-biased clinical history and lower diagnostic accuracy if the clinical history was bias. Their results also showed that with a correct clinical history, clinicians were more likely to report features consistent with the correct diagnosis, but with an incorrect clinical history, they were more likely to not report features consistent with the correct diagnosis and would identify features that were consistent with both the correct and incorrect diagnosis.\textsuperscript{16} Norman et al. (1992) obtained similar results in radiographic interpretation and Brooks et al. obtained similar results using photographs of patients presenting obvious typical physical features. These studies further support that the presence or absence of specific diagnostic features is not a good predictor of the diagnostic accuracy of clinician; as well, the identification of specific features present on an image may vary according to the diagnosis under consideration.\textsuperscript{17,18} This initial diagnostic hypothesis, which might be derived from non-analytic processing, may significantly impact the diagnostic accuracy of the clinician.

1.8 Testing Condition and Diagnostic Accuracy

While most studies have evaluated the impact of the testing condition (favoring analytic or non-analytic processing) only, Baghdady et al. (in press) evaluated the combined effect of processing (analytic and non-analytic) and learning approach (basic science and structured algorithm) on the diagnostic accuracy of novice clinicians. Undergraduate dental and dental hygiene students were taught four potentially confusable radiographic abnormalities with either the basic science or a structured algorithm. Participants were randomly divided between the two testing conditions and instructed to interpret the radiographs first before listing the different features present (favouring non-analytic processing), or to list the features present before interpreting the radiograph (favouring analytic processing). Overall, the students instructed to interpret the radiographs first before listing the radiographic features (non-analytic processing approach) had higher diagnostic accuracy than the students instructed to list the features present before interpreting the radiograph (analytic processing approach), and this was seen regardless of the learning condition (basic science or structured algorithm).\textsuperscript{19} As well, the superior diagnostic performance of the basic science learning approach seen in Baghdady et al 2009 study appears to have been mitigated when the students are forced to adopt a specific approach while interpreting an image. Similarly, other studies have shown the value of non-analytic processing.\textsuperscript{3,20} However, there is
no agreement concerning the processing approach that should be used with novice clinicians. Some argue that a systematic or analytic approach should be used to prevent cognitive bias, premature closure of decision, and failure to consider all the features present.\textsuperscript{17,18,21-29} However, there is evidence that a more holistic, non-analytic approach where an impression is made and followed by a deliberate search for features supporting the initial impression may be favourable.\textsuperscript{5,20,30} This first impression may be the result of recognition of a previously encountered pattern. While some may argue that the success of this approach is limited by the novice clinicians’ limited experience, Norman \textit{et al.} (1999) showed that even with limited experience, novice clinicians can successfully use a non-analytic reasoning strategy. In this study, undergraduate psychology students were instructed to interpret electrocardiograms with either an analytic or a non-analytic approach. Students who were instructed to give a diagnosis first before identifying the features present had a significantly higher diagnostic accuracy than the students who were taught to carefully identify the different features present before interpreting the image.\textsuperscript{20} In a similar study, Ark \textit{et al.} (2006) instructed a third group of participants to use a combined reasoning strategy. This third group was instructed to trust familiarity but to double check this first impression by carefully considering all the features. The combined strategy group outperformed the analytic and non-analytic groups.\textsuperscript{31}

1.9 Statement of the Problem

The cognitive process by which novice clinicians arrive at an interpretation is still unclear. There is evidence to suggest that non-analytic reasoning can be successfully used by the novice clinicians, and that knowledge of basic science mechanism can contribute positively to this reasoning. However, no previous study in oral radiology has systematically examined the interaction between learning approaches (basic science and structured algorithm) and processing (analytic vs. non-analytic) on the diagnostic accuracy of these clinicians, using speed-focused condition to favor non-analytic processing and accuracy-focused condition to favor analytic processing.

1.10 Study Aims

The aim of this study is to further characterize the role of basic science knowledge in diagnostic oral radiology. With novice clinicians, we wanted to determine if teaching the basic science behind an abnormality would allow the student to successfully use a holistic and non-analytic
processing approach to interpret and diagnose pathologies present in the image. If the knowledge of basic science helps a novice clinician to arrive at a diagnosis without analyzing the individual features, this could have an impact on the teaching strategies used with dental students and further support the value of basic science in dental education, as well as its role in the development of expertise.

With the experienced clinicians, we wanted to determine the effects of two different testing conditions on their diagnostic accuracy. We also want to determine if the basic science knowledge of the experienced clinicians is a predictor of their diagnostic performance. If we can gain further understanding of the experts’ approach to image analysis, this could guide teaching and testing strategies used with novice clinicians. If the testing strategy has no impact on their diagnostic accuracy, it may support the hypothesis that experts use a combination of the two processing approaches (analytic and non-analytic), which in turn can guide teaching novices.

1.11 Objectives

1. To evaluate the interaction between processing (analytic and non-analytic) and learning approaches (basic science and structured algorithm) on the diagnostic accuracy of novices clinicians.

2. To evaluate the effect of processing approaches (analytic and non-analytic) on the diagnostic accuracy of experienced clinicians.

1.12 Hypothesis

1. The diagnostic accuracy of novice clinicians who learned about four confusable diseases using a basic science approach is higher than the novice clinicians who learned about the same four diseases using the structured algorithm approach.

2. The diagnostic accuracy of novice clinicians in the basic science group is higher when speed is the principal focus of the testing condition, than when the accuracy is the principal focus of the testing condition.
3. The diagnostic accuracy of novice clinicians in the structured algorithm group is higher when accuracy is the principal focus of the testing condition, than when the speed is the principal focus of the testing condition.

4. The diagnostic accuracy of experienced clinicians is similar under speed-focused and accuracy-focused testing conditions.
Chapter 2

2 Material and Methods

2.1 Participants

2.1.1 Novice Clinicians

Undergraduate dental students from the Faculty of Dentistry Class of 2016 at the University of Toronto and second-year dental hygiene students from George Brown College were invited to participate in the study. For the purposes of the experiment, both groups were considered “novice clinicians”. This specific population was chosen because they already had lectures on radiation physics and biology, and an introduction to intraoral radiography and normal radiographic anatomy. In addition, both groups had enough knowledge of dentistry to understand four different and potentially confusable radiographic entities, but hadn’t yet received any lectures or formal instruction on radiographic interpretation of abnormalities. Analysis of previously collected data from Baghdady et al. (2009) using the same material and a similar cohort of students indicated that a sample of 27 participants in each learning condition would be sufficient to detect a 0.13 difference in mean score with a pool standard deviation of 0.17 using a two-tailed t-test of the difference between means, a power of 80%, and a significance level of 5%. The calculation was based on the assumption that the mean scores would be normally distributed. We aimed to enroll a total of 60-65 students, and they were randomly assigned using computer software into two equally-proportioned groups.

- Group 1: Participants were taught the four confusable diseases using a structured algorithm.
- Group 2: Participants were taught the four confusable diseases using a basic science algorithm.

For the University of Toronto dental students, a 5% bonus mark on their final examination of their radiology course (DEN317Y1) was offered for their participation in the study. Ethics board approval was obtained from the Health Sciences Research Ethics Board at the University of Toronto (Appendix A), and from the Applied and Institutional Research Ethics Board at the George Brown College (Appendix B).
All novice clinicians were recruited via email notices. The University of Toronto dental students were instructed to contact the primary investigator to schedule an appointment to participate in the study. The George Brown College students were informed of the time and location of the study. A total of 132 participants were enrolled in the study; 72 dental students from University of Toronto and 60 dental hygiene students from George Brown College. Please refer to the CONSORT flow diagram in Appendix C for details about how participants were recruited and assigned during the course of the study.

2.1.2 Experienced Clinicians:

Second- and third- year American oral radiology residents as well as oral radiologists who graduated from an American and Canadian oral and maxillofacial radiology graduate program after 2008 were enrolled as the “experienced clinicians” for this study. This population of participants was chosen because they have as a primary interest, the radiographic interpretation of abnormalities with sufficient experience to provide contrast to the novice clinician participants. A convenience sample size of twenty participants was enrolled in this sub-group of participants.

Participants were approached by email notification prior to the American Academy of Oral and Maxillofacial Radiology annual meeting in Beverly Hills, California in November, 2013. These individuals were instructed to contact the primary investigator prior to the meeting to schedule an appointment at the exhibition booth. There was no compensation for this group.

2.2 Materials

All learning and testing materials were presented using a computer program created using the Revolution software version 3.5.1 (Runtime Revolution Ltd. Edinburgh, Scotland).

2.2.1 Learning material

2.2.1.1 Novice Clinicians

Only the novice participants were required to go through the learning phase. The participants were taught four different and potentially confusable radiographic abnormalities using the same teaching materials used previously by Baghdady et al. (2009). This learning material was computer-based and consisted of a set of slides with audio recordings. The radiographic
abnormalities included were: periapical osseous dysplasia (a bone dysplasia), dense bone island (an osseous hyperplasia), periapical sclerosing osteitis (an inflammatory lesion) and complex odontoma (a hamartoma).

Two different sets of slides with audio recordings were used for the two learning conditions (structured algorithm or basic science). Participants in the structured algorithm group were taught using the five step analytic approach described in the book: “Oral Radiology: Principle and Interpretation” by White and Pharoah. This analysis includes localization of the abnormality, assessment of the periphery, the shape, the internal structure, and the effect of the entity on the surrounding structures. Participants in the basic science learning condition were taught the same radiographic features however, they were also taught the physiopathology behind the abnormality. The content of the learning material was based on the radiographic features and the basic science explanation stated in the textbook: “Oral Radiology: Principle and Interpretation” by White and Pharoah². In total 10 images were shown to the participants in the learning phase.

2.2.1.2 Experienced Clinicians:

There was no learning material for the experienced clinicians as they had already learned about the four abnormalities included in this study.

2.2.2 Testing material

2.2.2.1 Novice Clinicians

Participants went through two different tests:

1) Supplemental test: this test took place immediately after the students completed the learning phase. The purpose of this test was to ensure that the students understood the four different abnormalities before they moved on to the diagnostic test. The supplemental test consisted of ten true or false questions. There were two different supplemental tests which were specific for the learning condition used.

Examples of questions used for each learning condition:

Basic Science Group:

- Dense bone islands are considered to be a benign tumor. (F)
Structured Algorithm Group:

- The internal structure of a complex odontoma is totally radiopaque. (F)

2) Diagnostic ability test: this multiple choice test followed the supplemental test. The students went through a randomized series of 32 cases divided into 2 subsets, each of which contains 16 cases. Each subset contained four cases of each disease included in the study. There were specific instructions given to the participants before each section (see procedure section).

2.2.2.2 Experienced Clinicians:

Participants went through two different tests:

1) Diagnostic ability test: the experienced clinicians went through the same randomized series of 32 cases given to the novice clinicians. The average response time for each case was calculated in order to evaluate whether the participants in each testing condition followed the instructions.

2) Comprehension test: this multiple choice test took place immediately after the diagnostic ability test. The purpose of this test was to evaluate the basic science knowledge of the experienced clinicians on the four abnormalities included in the diagnostic ability test.

Example of questions used in the comprehension test:

Which sentence best describes periapical osseous dysplasia?

a- It’s a benign neoplasm and therefore has an unlimited growth potential. (F)

b- It’s a bone dysplasia and therefore represents a localized change in bone metabolism. (T)

c- It’s a reactive lesion and therefore necessitates a stimulus to occur. (F)

d- It’s a hamartoma and therefore has a limited growth potential. (F)
2.2.3 Procedure

2.2.3.1 Novice Clinicians

University of Toronto dental students participated in small cohorts with a maximum number of 6 participants per cohort. George Brown College dental hygiene students were divided in 2 groups of approximately 30 students each. Each novice participant was given a unique participant identifier and randomly assigned to a learning condition, using Research Randomizer© (G. C. Urbanick and S. Plous). They were then instructed to complete the learning phase, the supplemental test and the diagnostic test in one sitting. The diagnostic test was divided into two sections.

- Section 1: Participants were instructed to go through the diagnostic test as quickly as they could (favoring non-analytic processing). This testing condition was referred to as the speed-focused testing condition.
- Section 2: Participants were instructed to take their time while going through the diagnostic test and to focus on the accuracy of the diagnosis (favoring analytic processing). This testing condition was referred to as the accuracy-focused testing condition.

All participants were required to complete both sections, however, the order of each section was randomly determined with the two permutations distributed equally across the students in each learning condition using Research Randomizer© (G. C. Urbanick and S. Plous). The order of the testing condition was randomly determined for each student within their learning condition. Fifty two participants were assigned to the “speed-focused condition first group” and 53 participants were assigned to the “accuracy-focused condition first group”.

2.2.3.2 Experienced Clinicians

Experienced participants were assigned to a computer. Each participant was given a random study number. They went through the diagnostic test and the comprehension test in one sitting. The diagnostic ability test contained the same two sections as the one given to the novice clinicians (speed-focused condition or accuracy-focused condition). The order of each section was randomly distributed throughout the participants, using Research Randomizer© (G. C. Urbanick and S. Plous). All participants recruited in the study had to complete both sections. A total of 20 experienced clinicians were enrolled in the study: 9 participants were randomly
assigned to complete the accuracy-focused condition first and 11 participants completed the speed-focused condition first. Please refer to the CONSORT flow diagram in Appendix D for details about how participants were recruited and assigned during the course of the study.

2.2.4  Data Analysis

All statistical analysis was performed using IBM SPSS® statistics software version 22 (SPSS Inc., Chicago, IL).

2.2.4.1  Novice Clinicians

The data collected were the scores of each participant on the supplemental test and on the diagnostic ability test. For each student, the percentage of correct answers was calculated for each test. The response time of each participant for each question was also collected.

Prior to completing the final analysis an outlier analysis was performed. The data of students who scored more than 2 standard deviations below the average score on the diagnostic ability test were not included in the statistical analysis. Please refer to the CONSORT flow diagram in Appendix C for details about how the participants were handled during the course of the study.

2.2.4.1.1  Diagnostic Ability Test

A 2X2X2 repeated measures ANCOVA was used to evaluate the effect of learning condition (basic science vs structured algorithm) and testing condition (speed-focused vs. accuracy-focused) on diagnostic ability test scores. The supplemental test was used as a covariate in the ANCOVA to control for the level of comprehension of the learning material by the participants. These analyses used learning conditions and the order of the testing conditions (speed-focused condition first vs. accuracy-focused condition first) as between-subject variables and the testing condition as a within-subject variable. An assumption check was performed to verify that the score of the supplemental test and the learning condition were independent.

Two post-hoc ANCOVAs with the supplemental test as a covariate, the learning condition and the order of the testing condition as between-subject variables and either the speed-focused condition or the accuracy-focused condition as a dependent variable were performed.
2.2.4.1.2 Time Spent per Case

A 2X2X2 repeated measures ANCOVA was used to evaluate the effect of learning condition (basic science vs structured algorithm) and testing condition (speed-focused vs. accuracy-focused) on the average time spent per case. These analyses used learning condition and the order of the testing conditions (speed-focused condition first vs. accuracy-focused condition first) as between-subject variables and the testing condition (speed-focused vs. accuracy-focused) as a within-subject variable.

2.2.4.1.3 University of Toronto Dental Students versus George Brown College Dental Hygiene Students

2.2.4.1.3.1 Score on the Diagnostic Ability Test

A 2X2X2 repeated measures ANCOVA was used to evaluate the effect of educational background (university of Toronto vs. George Brown College), learning condition (basic science vs. structured algorithm) and testing condition (speed-focused vs. accuracy-focused) on diagnostic ability test score. The supplemental test was used as a covariate in the ANCOVA to control for the level of comprehension of the learning material by the participants. These analyses used educational background, learning conditions and the order of the testing conditions (speed-focused condition first vs. accuracy-focused condition first) as between-subject variables and the testing condition as a within-subject variable.

2.2.4.1.3.2 Time Spent per Case

The same analysis described in the previous section was performed using the average time spent per cases in each testing condition (speed-focused and accuracy-focused conditions) as a within-subject variable.

2.2.4.2 Experienced Clinicians

2.2.4.2.1 Score on the Diagnostic Ability Test

To ensure that the performance of the experienced clinicians was superior to that of novice clinicians, a 2X2 repeated measures ANOVA on the mean scores of the diagnostic ability test using the level of expertise (novice clinicians and experienced clinicians) as a between-subject
variable and the testing conditions (speed-focused vs. accuracy-focused) as a within subject-variable.

To evaluate if there was a significant difference on the diagnostic ability tests depending on the testing conditions (accuracy-focused or speed-focused condition first), 2X2X2 repeated measures ANCOVAs on the mean scores using the comprehension test as a covariate were performed. These analyses used the order of the testing conditions as the between-subject variables and the testing conditions (speed-focused vs. accuracy-focused) as a within-subject variable.

2.2.4.2.2 Time Spent per Case:

To determine whether the experienced participants followed the instructions, the average time spent per case of each participant in the two different testing conditions was calculated. To verify if the participants were faster in the speed-focused condition than in the accuracy-focused condition a paired t-test was used.
Chapter 3

3  Results

3.1 Novice Clinicians:

A total of 83 participants were included in the final analysis. A total of 49 participants were excluded from the final analysis representing 37.12% of overall participants. Twenty seven participants were excluded because their data were not saved on the computer. Sixteen participants were excluded because they didn’t follow the instructions given during the diagnostic ability test; specifically, these participants’ average time spent per case was shorter in the accuracy-focused condition than in the speed-focused condition. Six participants were also removed during the outlier analysis. Their score on the diagnostic ability test or the supplemental test were lower than the mean score minus 2 times the standard deviation. The assumption check revealed no interaction between the learning condition and the score of the supplemental test (F (1,78) = 3.50, p = 0.07). The mean score on the supplemental test for students taught with basic science learning approach was 7.95 ± 1.80 and the mean score on the supplemental test for students taught with structured algorithm learning approach was 7.17 ± 1.93.

3.1.1 Score on the Diagnostic Ability Test:

The results of the diagnostic ability test are summarized in Table 1. Learning condition (basic science vs. structured algorithm), testing condition (speed-focused vs. accuracy-focused) and the order of the testing condition (speed-focused first vs. accuracy-focused first) were shown to significantly affect the diagnostic accuracy of the novice clinicians in a three-way interaction (F (1,78) = 4.82, p = 0.05). Post-hoc analysis revealed that in the speed-focused testing condition, there was a significant interaction between learning condition and order of testing condition (F (1,79) = 4.29, p = 0.04). More specifically, the average score on the diagnostic ability test for students taught with basic science learning approach was significantly higher when speed-focused testing condition was the first condition experienced by the students. However, the average score on the diagnostic ability test for students taught with structured algorithm learning approach was significantly higher when speed-focused condition was the second condition.
experienced by the students. The results of the diagnostic ability test in speed-focused condition are summarized in Figure 1.

Post-hoc analysis revealed no interaction between the learning condition and the order of the testing condition in accuracy-focused condition (F (1,79) = 0.00, p = 0.96). The result of the diagnostic ability test in accuracy-focused condition is summarized in Figure 2.

3.1.2 Time Spent per Case

We found a significant difference in the mean time spent per case for the participants in the speed-focused condition (3.46 ± 1.55 s) and the participants in the accuracy-focused condition (6.19 ± 2.97 s) (F (1,80) = 20.07, p ≤ 0.01). This suggests that participants followed the instructions regarding speed and accuracy. Table 2 summarizes the mean time spent per case and standard deviation (seconds) for the novice clinicians on the diagnostic ability test depending of the learning condition, the testing condition and the order of the testing condition. Figure 3 summarizes the mean time spends per case (seconds) on the diagnostic ability test in speed-focused condition according to the learning condition and the order of the testing condition. Figure 4 summarize the mean time spent per case (seconds) on the diagnostic ability test in accuracy-focused condition according to the learning condition and the order of the testing condition.

3.1.3 University of Toronto Dental Students versus George Brown College Dental Hygiene Students

3.1.3.1 Score on the Diagnostic Ability Test

The ANCOVA revealed no significant difference in the score of the diagnostic ability test between the University of Toronto dental students (68.90 ± 1.70%) and the George Brown College dental hygiene students(65.50 ± 1.70%) (F(1,78)= 1.09, p = 0.30).

3.1.3.2 Time Spent per Case

The ANCOVA showed a significant difference in the mean time spent per case for the University of Toronto dental students (4.20 ± 0.24 s), who took longer than the George Brown College dental hygiene students (2.96 ± 0.36 s) (F(1, 78) = 52.69, p < 0.01).
3.2 Experienced Clinicians

3.2.1 Score on the Diagnostic Ability Test

Overall, the experienced clinicians (89.55 ± 1.80%) displayed a higher diagnostic ability than the novice clinicians (68.23 ± 2.11%) (F (1, 100) = 53.28, p < 0.01).

The experienced clinicians performed similarly in each testing condition (speed-focused and accuracy-focused conditions) and no two-way interaction was found between testing conditions and the order of the testing conditions (F (1,17) = 0.25, p = 0.63). The mean scores (percent correct) and standard deviation on the diagnostic ability test depending on the testing condition and the order of the testing condition are summarized in Figure 5.

The effect of the covariate (comprehension test) approach significance (F (1,17) = 3.94, p = 0.06). There is a trend observed between the score of the diagnostic ability test and the score of the comprehension test. The lack of significance may be attributed to the low power (0.47) of the statistical test observed.

3.2.2 Time Spent per Case:

The average time per cases spent by the participants between the different testing conditions (speed-focused and accuracy-focused) were not significantly different (t(19)=-1.56, p=0.14). However, there was a significant interaction between the average time spent per case and the order of the testing condition (F (1,17) 7.81, p = 0.01). Participants completed the second part of the diagnostic ability test significantly faster than the first part of the test, and this was independent of the testing condition (speed-focused or accuracy-focused conditions) they experienced. The average time spent per case (seconds) and standard deviation on the diagnostic ability test depending on the testing condition and the order of the testing condition are summarized in Figure 6.
Chapter 4

4 Discussion

4.1 General Discussion

4.1.1 Novice Clinicians

Overall, we predicted that novice clinicians taught with the basic science approach would have a higher diagnostic accuracy than novice clinicians taught with a structured algorithm. However, the results did not support this hypothesis as we failed to find a significant main effect of learning approaches. In previous work by Baghdady et al. (2009), the different learning approaches (basic science, structured algorithm and feature list) were compared. The students in the basic science group outperformed students in the structured algorithm group and in the feature list group. The authors suggested that the knowledge of the basic science underpinning the abnormality may have helped the novice clinicians develop a more coherent mental representation of the disease. Instead of relying on rote memorization of the different features, basic science may have enabled the novice clinicians to identify the radiographic features in a more coherent manner. However, in their study, there was no specific instruction given to the participants before the diagnostic ability test that might have pushed them towards a specific type of processing (i.e. analytic or non-analytic processing). In another study by Baghdady et al. (in press) looking at the effects of non-analytic and analytic processing on diagnostic accuracy, participants were instructed to either make a diagnosis first and then to identify the radiographic features (favoring non-analytic processing), or to identify the features first and then commit to an interpretation (favoring analytic processing). They found no advantage for the basic science learning condition. The authors attributed this result to the instructions which essentially “forced” participants to adopt a specific diagnostic/processing approach disrupting their unconscious choice of approach that might have fit best with their learning condition. In our study, the instructions given to the participant as well as the sequence by which participants were going through the two sections of the diagnostic ability test might have also disrupted the innate type of processing that would fit best with the learning condition.

In the present study, we also predicted that the diagnostic accuracy of the novice clinicians in the basic science group would be higher in the speed-focused condition than in the accuracy-focused
condition, and that the diagnostic accuracy of the novice clinicians in the structured algorithm group would be higher in the accuracy-focused condition than the speed-focused condition. Knowledge of underlying mechanisms (i.e. basic science instruction) is hypothesized to allow novices to engage in non-analytic processing, and instructing students to focus on the speed of diagnosis rather than accuracy was more likely to capture this non-analytic approach. This hypothesis was derived from previous work by Woods et al. (2006) using a similar methodology. The authors demonstrated that the performance of students in the basic science group was slightly higher (4%) in the speed-focused condition (non-analytic processing) than in the accuracy-focused condition (analytic processing) and this difference was statistically significant. Their results also showed that the performance of students in the structured algorithm group was slightly higher (7%) in the accuracy-focused condition than in the speed-focused condition and this difference was also statistically significant. The difference in the performances of the students in the basic science group and the feature list group was attributed to how the students processed the features present. In the basic science group, the different features may have been dealt with in a more coherent manner (faster) instead of being processed individually (slower). In their study, the order of the testing condition (speed-focused condition first or accuracy-focused condition first) did not influence significantly the performance of the participants. However, the nature of the task and the complexity of the cases were different from our study. They used short and simple cases in order to decrease the possibility of obtaining a long response time from participants that could be attributed to slow reading speed and not slow diagnostic processing. In our study, as the participants were interpreting a radiographic image, no reading was necessary. More complex and challenging cases were included in our study with variations in the location, size and shape of the entities included, which may explain the difference in the results.

A previous study by Baghdady et al. (in press) using the same learning and similar testing materials demonstrated that students placed in the non-analytic testing condition had higher diagnostic accuracy than the students placed in the analytic testing condition, and this regardless of the learning condition used. However, important methodological differences between the two studies limit their comparison. They have used different strategy to elicit analytic and non-analytic processing. In their study, some participants were instructed to interpret the radiographs first before listing the different features present, arguably encouraging a non-analytic reasoning process. Others were asked to list the features present before interpreting the radiograph,
arguably encouraging an analytic reasoning process. As well, participants in each learning condition were randomly assigned to only one testing condition and did not experience the two different testing conditions. Therefore, the impact of the order of the testing conditions could not be evaluated. Similarly to previous studies, we used speed to control the attentional demand to the task, and to elicit analytic or non-analytic processing.\textsuperscript{10,32} Participants were asked to focus on the speed of their interpretation in order to encourage a non-analytic reasoning process, and to focus on the accuracy of their interpretation to encourage an analytic reasoning process. The results revealed that in the speed-focused testing condition, there was a significant interaction between learning condition and order of testing condition. More specifically, participants in the basic science group had the highest average score on the diagnostic ability test in the speed-focused condition when this condition was the first condition experienced by the participants. However, participants in the structured algorithm group had the highest average score on the diagnostic ability test in the speed-focused condition when this condition was the second condition experienced by the participants. Therefore, it appears that under a specific set of conditions, non-analytic processing might successfully be used by novice clinicians. When students are taught with the basic science approach, they can successfully use non-analytic processing if this condition is the first one they experience during the diagnostic ability test. However, if students are taught with the structured algorithm approach, they appear to benefit from some practice before they can successfully use non-analytic processing.

Participants taught with the basic science approach performed better in the speed-focused condition only when this was the first condition they experienced. As other studies suggested, the knowledge of the basic science seems to have worked best with a non-analytic processing approach.\textsuperscript{6,7,33,34} However, this benefit was lost when students were instructed to focus on the accuracy of their interpretation during the first part of the test. This could be the result of a disruption in the participants’ spontaneous cognitive process when instructed to take their time and focus on the accuracy of their interpretation. Instead of looking at the radiographic image as a whole, the clinicians might focus on the identification of the different features. This may result in disruption of the coherent mental representation of a disease where the different radiographic features present make sense to them. Thus, the benefit from the basic science learning condition may be very sensitive to the testing instructions given to participants.
Students taught with the structured algorithm had their highest average score in the speed-focused condition when this condition was the second condition they experienced. This may be the result of practice. Students who are taught with a structured algorithm need to apply the five-step analytic approach described in the learning material. The radiographic interpretation is then based on the different features that the students collect during the structured analysis of the image. As students were interpreting 16 cases in the accuracy-focused condition first, they had some practice on feature identification and radiographic interpretation. This may allow novice clinicians to deal with the radiographic features in a more coherent manner. Another explanation might be derived from previous research in pure motor skill domain. Beilock et al. looked the putting accuracy of novice and expert golfers in speed-focused condition. Experts putting accuracy improved when they were instructed to put as fast as they can. Expert putting performance is easily and rapidly accessible, and is also less affected by different instructional methodologies. In contrast, the accuracy of novice golfers declined under the speed-focused condition. The authors suggested that the difference in performance between the two groups was due to the integration and automaticity of skill acquisition that was present in experts but absent in novices. With the acquisition of expertise, a more rapid and automated process occurs and less attention and time to the task is necessary. Although a cognitive task such as the interpretation of a radiograph is different from a motor skill task, there may be some similarities. Students taught with a structured algorithm may need to practice the application of the algorithm learned and the interpretation of the different features before it becomes more automatic. After sufficient practice, radiographic interpretation may require less time to be performed and students might use non-analytic processing. Similarly, other studies in radiology support that with practice clinicians move from a “search-to-find” (analytic) approach to a more efficient holistic (non-analytic) approach. This qualitative shift that seems to occur with expertise may explains the performance of novice clinicians taught with the structured algorithm.

This study further supports the concept that rapid, non-analytic processing approach is not associated with decreased diagnostic accuracy. This finding has been noted in a number of other studies. For instance, looking at the response time at five different levels of expertise in dermatology, Norman et al. found that erroneous diagnosis was associated with longer response times and correct diagnosis with shorter response times. In radiology, Kundell et al. studied the relationship between the search time required to first locate a cancerous lesion and the diagnostic
performance of mammographers at different levels of expertise. In this study using an eye tracking device, overall the observers took about 1 second to identify and fixate on half of the subtle cancers. Their results suggested that a holistic perception of the radiographic image may enable the clinician to identify an abnormality more rapidly and accurately. However, important differences were noted depending on the experience of the clinicians. Less experienced clinicians were not able to use a holistic approach to image analysis to identify an abnormality. These individuals were left to search the entire radiographic image for a perturbation, use a more analytic process to evaluate the features present, and determine if the perturbation was a true abnormality. This further supports that a holistic, non-analytic processing approach to image analysis may be a component of expertise in radiographic interpretation.

Even though the performance on the diagnostic ability test between the University of Toronto dental students and the George Brown College dental hygiene students was not significantly different, there was a significant difference between the average times spent per case. This may reflect the difference in the setting of the testing conditions between the two institutions. University of Toronto dental students participated in the study in groups of 4 to 6 students and the George Brown College dental hygiene students participated in group of 26 to 34 students. Because the dental hygiene students were recruited in larger groups, pressure to finish the test quickly may have influenced the behaviors of these students.

4.1.2 Experienced Clinicians

In this study, the instruction given to the experienced clinicians did not influence their performance on the diagnostic ability test. This is consistent with the result we predicted. Norman (2005) suggested that expertise is associated with “multiple coordinated representation in memory” that can vary from pattern recognition to using the basic science knowledge underlying the abnormality. These multiple representations would be used in different situations but the reason why one or another is utilized in a specific context is not well understood. Previous studies with novice clinicians suggest that instruction to trust familiarity while carefully considering the features present (combined analytic and non-analytic processing approach) results in higher diagnostic ability and that the reliance on only one processing approach may result in decreased performance. Patel’s studies suggested that experts are able to select pertinent features and formulate a hypothesis early after a clinical case is presented to them. The
remaining time spent on a case would be to refine and confirm the diagnostic hypothesis with the features present.\textsuperscript{43} In our study, the experienced clinicians were not able to follow the instructions given to them. More specifically, they were not able to go faster in the speed-focused condition than in the accuracy-focused condition. This may reflect the different reasoning strategies available to them during the interpretation process depending on the complexity of the case presented to them.

Although not found to be statistically significant, the data showed a trend between the score of the diagnostic ability test and the score of the comprehension test. The lack of significance may be attributed to the low power (0.47) of the statistical test observed. The comprehension test aimed to assess the knowledge of the participants on the basic science underlying the abnormalities included in the study. Therefore, the results suggest that knowledge of the disease mechanism underpinning the abnormality may help the clinicians during the interpretation process. Several studies have attempted to evaluate the association between the basic science knowledge and the diagnostic accuracy of experts. Patel’s study, using a “think-aloud” protocol found that experts focused on the analysis of the clinical features of a disease and made very little inference from the basic science knowledge. However, when clinicians were faced with more complex problems, they tended to rely more on basic science knowledge.\textsuperscript{43,44} Studies by Schmidt et al. have also shown that experts, when asked to think aloud, make little inference from the basic science concepts. The authors attribute these results to gradual integration of the basic science knowledge with the clinical knowledge, referring to this process as “knowledge encapsulation”.\textsuperscript{8} Looking at the radiographic interpretation of straightforward cases, Lesgold et al. found an association between the diagnostic accuracy of the resident and expert radiologists on chest radiographs and their analytic processing of biomedical knowledge. As well, experts were more accurate and made more connection between the radiographic findings and their basic science knowledge.\textsuperscript{13} The knowledge of the basic science underpinning the abnormality appears to help the clinician during the interpretation process. This may explain trend observed in our study between the basic science knowledge of experience clinicians and their diagnosis accuracy.
4.2 Implications

4.2.1 Novice Clinicians

From an academic standpoint, it is important to determine and understand the role of processing and learning approaches used with novice clinicians. Traditionally, non-analytic processing was associated with pattern recognition. To avoid diagnostic error resulting from confusion of similarly appearing abnormalities, cognitive bias and premature closure of decision, novice clinicians were discouraged from using non-analytic processing during interpretation. Students were encouraged to take their time to identify all the features present before interpreting the radiograph (analytic processing). This study has shown that non-analytic processing approach can be used by novice clinicians.

This study has also shown that the timing of instruction of a processing approach (analytic vs. non-analytic processing) during the interpretation test and the learning approach (basic science vs. structured algorithm) used may impact their performance of the novice clinicians on the diagnostic ability test. The basic science learning approach may enable the novice clinicians to deal with the radiographic features in a more coherent manner and result in higher diagnostic accuracy when instructed to focus on their speed of their interpretation (non-analytic processing) first. Instructions to focus on the accuracy of their interpretation (analytic processing) first seem to disrupt this coherence and result in lower diagnostic accuracy. The structured algorithm learning approach may favor a more analytic, feature-by-feature interpretation, and practice is necessary before the novice clinicians can deal with the radiographic features in a more coherent manner.

4.2.2 Experienced Clinicians

This study demonstrated that the performance on the diagnostic ability test was not influenced by the timing of instruction given to the experienced clinicians. This further supports that with expertise a clinician develop his own radiographic interpretation technique which is likely combines analytic and non-analytic processing. As well, instructions appear to not be sufficient to disrupt this process.
4.3 Limitations

4.3.1 NoviceClinicians

Although there was no significant difference between the performance on the diagnostic ability test of George Brown College dental hygiene students and University of Toronto dental students, George Brown College students were significantly faster. This might be due to the difference in the testing condition of the two student populations. University of Toronto dental students participated in groups of 4 to 6 students while George Brown College students participated were divided in groups of 26 and 34 students. The decreased supervision of each participants and the peer pressure to complete the study fast might have influencetheir performance.

Previous studies using the same material have shown that a large number of participants in each group is necessary to obtain significant result. \(^4,19,45\) The number of participants enrolled in the study may have affected the ability to detect a significant interaction between the learning condition and the testing conditions. The participants were divided in a total of four groups according to their learning conditions (basic science or structured algorithm) and the order of the testing conditions (accuracy-focused condition first or speed-focused condition first). Each group contained 16 to 27 participants (observed power = 0.53). With more participants in each group, a statistically significant interaction may have been present.

The nature of the task is artificial in the sense that the participants are asked to provide an interpretation of radiograph that presents an abnormality. However, in real life not all radiographs would present an abnormality. Students would need to look at the entire image and identify if an abnormality is present or not. Radiographic interpretation includes lesion detection (visual search, recognition of an abnormality) and interpretation (identification of the features present and a decision making process). \(^46\) This study focused on the last two steps as the abnormalities were already identified with arrows.

The students went through the learning and testing materials using a computer based program. This artificial setting does not reflect the classroom setting in which students usually learn the material. Therefore the results do not consider limitations inerrant to classroom setting such as number of students per class, time constraint to cover the material and the difference in the teaching style of lecturers.
4.3.2 Experienced Clinicians

For the experienced clinicians, the number of participants enrolled was limited and may have affected the ability to detect a significant interaction between the score on the diagnostic ability test and the score on the comprehension test (observed power = 0.47).

Another limitation is that the experienced clinicians had difficulty following the instructions. Of a total of 20 participants, 11 participants didn’t follow the instruction. This was occurring predominantly when they were instructed to focus on the speed of their interpretation first: participants had difficulty slowing down in the second part of the test. In fact, only 1 of the 11 participants was able to slow down in the accuracy-focused condition.

4.4 Future directions

4.4.1 Novice Clinicians

A future direction would be to continue the study to increase the sample size. With an increased sample size, it might not be necessary to include the score of the supplemental test as a covariate in the statistical analysis. Also, the trend observed with the experienced clinicians might reach significance.

Further research could also include using an eye tracking device during the learning phase and the testing phase of the study to further understand how the participants look at the radiographic features. Information on fixation-cluster dwell time may be used to measure visual information processing. More information about where the observer dwells to collect more information and resolve ambiguity might be a more accurate or a second indicator of analytic processing. As well, information about how the students are looking at the radiographic images may help to understand how the learning and processing approaches influence clinicians’ searching pattern or perceptions of radiographic features. In our study, we hypothesize that the students taught with the basic science approach might be able to deal with the radiographic features in a more coherent manner. More information about their search pattern could further support this assumption. Similarly, further understanding on the search pattern of students taught with the structured algorithm approach might provide some insight on the processing approach (analytic vs. non-analytic) used by the clinicians.
Another future direction could be to include adding a third testing condition. This third group would be instructed to look at the image and interpret the radiograph as fast as possible but to double check their first impression by looking for the features present (combined analytic and non-analytic processing). This third group would further explore the interaction between learning and diagnostic processing approaches. A study by Ark et al. compared the diagnostic accuracy of clinicians taught electrocardiogram interpretation using a combined, an analytic or a non-analytic approach. The results have shown that use of a combined approach would result in higher diagnostic accuracy.⁴¹

4.4.2 Experienced Clinicians

A future direction would be to use an eye tracking device during the diagnostic ability test. In our study, we hypothesize that with expertise, a clinician develops their own radiographic interpretation technique, and instructions appear to not be sufficient to disrupt this process. The eye tracking device might be a useful tool to further determine if the instructions given to participants during the diagnostic ability test have an impact on their search pattern during radiographic interpretation. If no change would be seen in the clinicians’ search pattern, this would further support that experienced clinicians develop their own radiographic interpretation technique and instructions may not sufficient to disrupt this process.
5 Conclusion

This study aimed to evaluate the interaction between different approaches to learning (basic science and structured algorithm) and processing (analytic and non-analytic). Diagnostic errors by novice clinicians were not associated with non-analytic processing (speed-focused testing condition). Instruction to focus on the accuracy of the interpretation (analytic processing approach) did not increase the diagnostic accuracy, and this was seen with both learning approaches. However, a significant interaction was seen between learning approaches and the sequence by which participants are introduced to analytic and non-analytic processing. This suggests that non-analytic processing might successfully be used only under specific set of conditions. Instructors should consider learning and processing approaches while designing training material. Moreover, our study demonstrates that learning approaches, processing approaches and their interaction must be considered in order to improve diagnostic accuracy of novice clinicians. As well, experienced clinicians may use multiple strategies combining analytic and non-analytic processing during the interpretation process. The effectiveness of a combined processing strategy with novice clinicians should be evaluated in order to determine if there would be a benefit to use both analytic and non-analytic processing approaches.
Table 1: Mean scores (percent correct) and standard deviation for the novice clinicians on the diagnostic ability test depending of the learning condition (basic science or structure algorithm), the testing condition (speed-focused or accuracy-focused condition) and the order of the testing condition (speed-focused or accuracy-focused condition first).

<table>
<thead>
<tr>
<th></th>
<th>Speed-focused testing condition first</th>
<th>Accuracy-focused condition second</th>
<th>Accuracy-focused condition first</th>
<th>Speed-focused condition second</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Science</td>
<td>75.39 ± 13.60 % (N=16)</td>
<td>67.19 ± 14.70 % (N=16)</td>
<td>65.28 ± 14.30 % (N=27)</td>
<td>65.05 ± 13.90 % (N=27)</td>
</tr>
<tr>
<td>learning condition</td>
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<tr>
<td>Structured</td>
<td>67.28 ± 15.20 % (N=17)</td>
<td>65.44 ± 19.40 % (N=17)</td>
<td>66.48 ± 12.30 % (N=22)</td>
<td>72.16 ± 12.60 % (N=22)</td>
</tr>
<tr>
<td>Algorithm learning</td>
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<tr>
<td>condition</td>
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</table>
Table 2: Mean time spent per case (seconds) and standard deviation for the novice clinicians on the diagnostic ability test depending of the learning condition (basic science or structured algorithm), the testing condition (speed-focused or accuracy focused condition) and the order of the testing condition (speed-focused or accuracy-focused condition first).

<table>
<thead>
<tr>
<th></th>
<th>Speed-focused condition (first)</th>
<th>Accuracy-focused condition (second)</th>
<th>Accuracy-focused condition (first)</th>
<th>Speed-focused condition (second)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Science n = 16</td>
<td>8.28 ± 3.92 s (N=16)</td>
<td>11.93 ± 6.67 s (N=16)</td>
<td>14.16 ± 6.65 s (N=27)</td>
<td>6.20 ± 2.49 s (N=27)</td>
</tr>
<tr>
<td>Structured Algorithm n = 17</td>
<td>7.42 ± 3.25 s (N=17)</td>
<td>9.51 ± 3.35 s (N=17)</td>
<td>12.75 ± 5.42 s (N=22)</td>
<td>6.39 ± 2.79 s (N=22)</td>
</tr>
</tbody>
</table>
Figure 1: Mean score (percent correct) for the novice clinicians on the diagnostic ability test (percent correct) in speed-focused condition according to the learning condition (basic science or structured algorithm) and the order of the testing condition (speed-focused condition first or speed-focused condition second).
Figure 2: Mean score (percent correct) for the novice clinicians on the diagnostic ability test in accuracy-focused condition according to the learning condition (basic science or structured algorithm) and the order of the testing condition (accuracy-focused condition first or accuracy-focused condition second).
Figure 3: Mean time spent per case (seconds) for the novice clinicians on the diagnostic ability test in speed-focused condition according to the learning condition (basic science or structured algorithm) and the order of the testing condition (speed-focused condition first or speed-focused condition second).
Figure 4: Mean time spends per case (seconds) for the novice clinicians on the diagnostic ability test in accuracy-focused condition according to the learning condition (basic science or structured algorithm) and the order of the testing condition (accuracy-focused condition first or accuracy-focused condition second).
Figure 5: Mean score (percent correct) for the experienced clinicians on the diagnostic ability test according to the testing condition (speed-focused and accuracy-focused condition) and the order of the testing condition (speed-focused or accuracy-focused condition first).
Figure 6: Mean time spent per case (seconds) for the experienced clinicians on the diagnostic ability test according to the testing condition (speed-focused or accuracy focused condition) and the order of the testing condition (speed-focused or accuracy-focused condition first).
Bibliography


Appendix A

Health Sciences Research Ethics Board at University of Toronto approval letter

UNIVERSITY OF TORONTO
OFFICE OF THE VICE PRESIDENT, RESEARCH

PROTOCOL REFERENCE # 28347

October 1, 2013

Dr. Nicole Woods
DEPT OF SURGERY
FACULTY OF MEDICINE

Dr. Catherine Nolet-Levesque
DEPT OF SURGERY
FACULTY OF MEDICINE

Dear Dr. Woods and Dr. Catherine Nolet-Levesque,

Re: Your research protocol entitled, “The role of speed and instructional strategy on diagnostic accuracy in oral radiology”

ETHICS APPROVAL

Original Approval Date: October 1, 2013
Expiry Date: September 30, 2014
Continuing Review Level: 1

We are writing to advise you that the Health Sciences Research Ethics Board (REB) has granted approval to the above-named research protocol under the REB’s delegated review process. Your protocol has been approved for a period of one year and ongoing research under this protocol must be renewed prior to the expiry date.

Any changes to the approved protocol or consent materials must be reviewed and approved through the amendment process prior to its implementation. Any adverse or unanticipated events in the research should be reported to the Office of Research Ethics as soon as possible.

Please ensure that you submit an Annual Renewal Form or a Study Completion Report 15 to 30 days prior to the expiry date of your current ethics approval. Note that annual renewals for studies cannot be accepted more than 30 days prior to the date of expiry.

If your research is funded by a third party, please contact the assigned Research Funding Officer in Research Services to ensure that your funds are released.

Best wishes for the successful completion of your research.

Yours sincerely,

[Signature]

OFFICE OF RESEARCH ETHICS
McLennan Building, 12 Queen's Park Crescent West, 2nd Floor, Toronto, ON M5S 1B8 Canada
Tel: +1 416 946-3273 • Fax: +1 416 946-5763 • ethics.review@utoronto.ca • http://www.research.utoronto.ca/research-administration/ethics
Appendix B

Applied and Institutional Research Ethics Board at the George Brown College approval letter

Dear Dr. Nolet-Lévesque

November 1, 2013

RE: REB file # 6003929 Title: The Role of Speed and Instructional Strategy on Diagnostic Accuracy in Oral Radiology.

Ethics Approval Date: November 1, 2013
Expiry Date: November 1, 2014.

We are writing to advise you that the Research Ethics Board (REB) has granted full approval to the above-named research study, for a period of one year. Please note that approval is based on the following:

a) Any unanticipated problems that increase risk to the participants must be reported to the REB immediately.
b) The study is approved for one year: if needed, apply for a renewal before the expiry date.
c) A study completion form must be submitted to the REB upon completion of the project.

The following documents have been approved for use in this study: the information letter and consent. Please insert the ethics approval number (6003929) into these documents. Each participant should receive a copy of his or her consent form.

Please quote your REB file number (6003929) on future correspondence.

Best wishes for the successful completion of your project.

Yours sincerely,

[Signature]

Sarah Evans, RN, MN, EdD
Chair, Research Ethics Board

cc: Applied and Institutional Research, George Brown College
   It is the responsibility of the Principal Researcher to keep the file complete and up-to-date at all times.

P.O. Box 1015, Station B, Toronto, Ontario, Canada M5T 2T9  416-415-2000  www.georgebrown.ca
Appendix C

CONSORT flow diagram for details about how novice clinicians were recruited and handled during the course of the study

Enrollment

Assessed for Eligibility (n=132)

Second year:
- University of Toronto dental students (n=72)
- George Brown College dental hygiene students (n=60)

Randomized (n= 132)

Allocation: Learning Conditions

Allocated to Basic Science Group (n=67)

Excluded (n=14)
- Data not saved on server (n=14)

Supplemental Test (n=52)
- Excluded (supplemental test < 25%) (n=1)

Allocated to Structured Algorithm Group (n=65)

Excluded (n=13)
- Data not saved on server (n=13)

Supplemental Test (n=50)
- Excluded (supplemental test < 25%) (n=2)

Diagnostic Ability Test

Analysed (n=17)
1) Speed-focused condition first
2) Accuracy-focused condition second
- Excluded from analysis (outlier analysis on diagnostic ability test score) (n=1)
- Excluded from analysis (manipulation check) (n=6)

Analysed (n=28)
1) Accuracy-focused condition first
2) Speed-focused condition second

Analysed (n=17)
1) Speed-focused condition first
2) Accuracy-focused condition second
- Excluded from analysis (outlier analysis on diagnostic ability test score) (n=1)
- Excluded from analysis (manipulation check) (n=9)

Analysed (n= 21)
1) Accuracy-focused condition first
2) Speed-focused condition second
- Excluded from analysis (outlier analysis on diagnostic ability test score) (n=1)
- Excluded from analysis (manipulation check) (n= 1)
Appendix D

CONSORT flow diagram for details about how experienced clinicians were recruited and handled during the study

1. **Enrollment**
   - Assessed for Eligibility (n=20)
     - Second and third year oral radiology residents and recently graduated radiologists

2. **Randomized (n=20)**

3. **Allocation: Diagnostic Ability Test**
   - Allocated to Intervention (n=11)
     - 1) Speed-focused condition first
     - 2) Accuracy-focused condition
   - Allocated to Intervention (n=9)
     - 1) Accuracy-focused condition first
     - 2) Speed-focused condition second

4. **Comprehension Test**
   - Comprehension Test (n=9)

5. **Analysis**
   - Analysed (n=11)
     - No participant excluded from analysis
   - Analysed (n=9)
     - No participant excluded from analysis
Copyright Acknowledgements

Thank you to Dr. Mariam Baghdady who let me use the learning and testing material that she has designed for her previous studies.