

Human Factors: The Journal of the Human Factors and Ergonomics Society

<http://hfs.sagepub.com/>

Eyes-On Training and Radiological Expertise : An Examination of Expertise Development and Its Effects on Visual Working Memory

Melissa R. Beck, Benjamin A. Martin, Emily Smitherman and Lorrie Gaschen

Human Factors: The Journal of the Human Factors and Ergonomics Society 2013 55: 747 originally
published online 27 December 2012

DOI: 10.1177/0018720812469224

The online version of this article can be found at:

<http://hfs.sagepub.com/content/55/4/747>

Published by:



<http://www.sagepublications.com>

On behalf of:



[Human Factors and Ergonomics Society](http://www.hfes.org)

Additional services and information for *Human Factors: The Journal of the Human Factors and Ergonomics Society* can be found at:

Email Alerts: <http://hfs.sagepub.com/cgi/alerts>

Subscriptions: <http://hfs.sagepub.com/subscriptions>

Reprints: <http://www.sagepub.com/journalsReprints.nav>

Permissions: <http://www.sagepub.com/journalsPermissions.nav>

>> [Version of Record](#) - Jul 12, 2013

[OnlineFirst Version of Record](#) - Dec 27, 2012

[What is This?](#)

Eyes-On Training and Radiological Expertise: An Examination of Expertise Development and Its Effects on Visual Working Memory

Melissa R. Beck, Benjamin A. Martin, Emily Smitherman, and Lorrie Gaschen,
Louisiana State University, Baton Rouge

Objective: Our aim was to examine the specificity of the effects of acquiring expertise on visual working memory (VWM) and the degree to which higher levels of experience within the domain of expertise are associated with more efficient use of VWM.

Background: Previous research is inconsistent on whether expertise effects are specific to the area of expertise or generalize to other tasks that also involve the same cognitive processes. It is also unclear whether more training and/or experience will lead to continued improvement on domain-relevant tasks or whether a plateau could be reached.

Method: In Experiment 1, veterinary medicine students completed a one-shot visual change detection task. In Experiment 2, veterinarians completed a flicker change detection task. Both experiments involved stimuli specific to the domain of radiology and general stimuli.

Results: In Experiment 1, veterinary medicine students who had completed an “eyes-on” radiological training demonstrated a domain-specific effect in which performance was better on the domain-specific stimuli than on the domain-general stimuli. In Experiment 2, veterinarians again showed a domain-specific effect, but performance was unrelated to the amount of experience veterinarians had accumulated.

Conclusion: The effect of experience is domain specific and occurs during the first few years of training, after which a plateau is reached.

Application: VWM training in one domain may not lead to improved performance on other VWM tasks. In acquiring expertise, eyes-on training is important initially, but continued experience may not be associated with further improvements in the efficiency of VWM.

Keywords: change detection, radiology, medical training

Address correspondence to Melissa R. Beck, Department of Psychology, Louisiana State University, Baton Rouge, LA 70803; e-mail: mbeck@lsu.edu.

HUMAN FACTORS

Vol. 55, No. 4, August 2013, pp. 747-763

DOI:10.1177/0018720812469224

Copyright © 2012, Human Factors and Ergonomics Society.

INTRODUCTION

In most difficult tasks, extensive training is necessary for one to reach a level of expertise that will facilitate a high level of performance and few errors (Ericsson, Krampe, & Tesch-Römer, 1993). For example, medical students receive extensive training to acquire the ability to detect abnormalities and changes in radiographs. Performing this visual change detection task requires maintaining information in visual working memory (VWM) to compare the information in one radiograph with the information in another. Although performance is rarely perfect because VWM capacity is limited (Alvarez & Cavanagh, 2004; Eng, Chen, & Jiang, 2005; Irwin, 1992; Irwin & Andrews, 1996; Levin, Simons, Angelone, & Chabris, 2002; O'Regan, 1992; Rensink, 2000; Simons, 1996; Simons & Levin, 1997; for review, see Simons & Rensink, 2005), performance can improve with training presumably because one uses VWM more efficiently by better organizing stored information and/or by storing retrieval cues for efficient access to information in long-term memory (LTM; Chase & Ericsson, 1981; Chase & Simon, 1973a, 1973b; Charness, 1976; Ericsson & Kintsch, 1995; Ericsson & Staszewski, 1989; Simon & Chase, 1973).

The current study addresses several knowledge gaps regarding the use of training to improve performance. First, it is unclear whether improvement in VWM performance may be specific to the area of expertise (Memmert, Simons, & Grimme, 2009; Waters, Gobet, & Leyden, 2002) or may generalize to VWM performance for tasks outside of the area of expertise (Green & Bavelier, 2003, 2006). Second, it is unclear the degree to which higher levels of experience within the domain of expertise are associated with more efficient use of VWM.

The present project addresses these knowledge gaps with regard to the field of radiology.

This issue is critical because it is important for educators, students, and professionals within medical fields to know the effects of training and experience on VWM. VWM is necessary when radiologists compare pretreatment and posttreatment radiographs to determine whether a diagnostic element (e.g., a fracture in a bone) of a radiograph has changed. It is expected that higher levels of training and experience will be associated with better performance when finding differences in radiographs. However, it is unknown how much training and/or experience is needed to show better performance. Furthermore, it is unknown whether training and experience with radiographs will generalize to tasks unrelated to reading radiographs. For example, if there is a general effect on VWM, then one might expect radiologists to also be able to detect changes in other types of visual stimuli efficiently and therefore require less training or experience when asked to complete new or unfamiliar tasks requiring VWM.

Is the Effect of Experience General or Specific?

Several studies have demonstrated that experts perform better on tasks within their area of expertise because they use a more efficient allocation of visual attention and have better memory performance (e.g., Christensen et al., 1981; Ferrari, Didierjean, & Marmèche, 2008; Jarodzka, Scheiter, Gerjets, & van Gog, 2010; Myles-Worsley, Johnston, & Simons, 1988). What the research does not agree on is whether this improvement in performance is specific to the area of expertise or whether it generalizes to other tasks that also involve visual attention and memory. On one side, there is research demonstrating that experts are better at tasks related to the area of expertise (domain-specific tasks) but not on tasks unrelated to the area of expertise (domain-general tasks), even if both tasks involve similar cognitive processes (e.g., attention and memory; Memmert et al., 2009; Waters et al., 2002). On the other side is research demonstrating that experts perform better on tasks that involve the cognitive processes important for the tasks in their area of expertise regardless of whether the task is domain specific or not (e.g., Green & Bavelier, 2003, 2006).

In support of the argument that expertise is not related to a general superiority of attention (Memmert et al., 2009) or VWM abilities (Waters et al., 2002), studies have demonstrated that expertise improves change detection performance for stimuli related to the area of expertise but not for unrelated stimuli or changes to nonmeaningful stimuli (Reingold, Charness, Pomplun, & Stampe, 2001; Werner & Thies, 2000). Werner and Thies (2000) reported that football experts detected changes that involved meaningful information in a football scene (e.g., the addition of a football in the scene) faster and more accurately than did novices. However, there was no difference in change detection performance between experts and novices for changes that involved nonmeaningful information in a football scene (e.g., changing the color of the referee's glove) or for changes to scenes unrelated to the area of expertise (e.g., traffic scenes). In addition, chess experts detected changes to the meaningful chess configurations more quickly than did novice and intermediate players (Reingold et al., 2001). However, no performance differences were observed among the groups for the random chess configurations. These studies suggest that expertise does not improve the general efficiency of VWM but, rather, specific knowledge stored in LTM relevant to the area of expertise is used to allocate attention and VWM recurses more efficiently for stimuli related to the domain of expertise.

Contrary to research demonstrating improvement in performance only on expertise-related tasks, other research indicates a unidirectional relationship between expertise and general visual attention abilities. Specifically, although it is not known whether training on general visual attention abilities leads to better video game performance, training in video games does lead to better general visual attention performance (Green & Bavelier, 2003, 2006; Hubet-Wallander, Green, Sugarman, & Bavelier, 2011). Green and Bavelier (2003, 2006) demonstrated that avid action video game players have a broader scope of attention and a larger capacity for attention than do people who are not video game players. This effect was found for non-video game tasks, such as identifying the

presence of a target shape among several distractor shapes. Although this task requires similar processes as action video games, the stimuli and context are quite different. Additionally, participants who were not video game players who were trained for 30 hr on action video games began to exhibit levels of performance similar to those of video game players on the non-expertise-relevant tasks (Green & Bavelier, 2006). The results from these studies are indicative of a general improvement in visual attention capabilities for expert video game players as well as for people who are not video game players who are trained on action video games. Although general levels of improvement have been found in attention tasks, they have not, to our knowledge, been indicated in tasks that involve VWM.

Within the area of radiology expertise, the research is also mixed as to whether expertise leads to a specific or more general improvement in performance, and, to our knowledge, none of the research has involved examination of the effects of radiology expertise on VWM tasks. A specific effect of expertise on VWM seems logical if the improvement in performance is related to the ability to use relevant medical knowledge to improve the efficiency of VWM when comparing two radiographs. Lesgold et al. (1988) demonstrated that expertise is associated with an improvement in LTM related to the area of expertise. This improvement in LTM could also lead to a more efficient use of VWM but only on domain-specific tasks. Research supporting a specific effect of expertise demonstrated that there is not a significant relationship between experienced radiologists' ability to accurately locate pulmonary nodules and their performance on tests of visual perception (e.g., an embedded-figures test; Bass & Chiles, 1990). Furthermore, radiologists did not differ from the general population in success in performing two visual search and target detection tasks that required the same type of visual skill as medical diagnostics (Nodine & Krupinski, 1998). These studies suggest a specific effect on visual attention and target detection tasks but do not provide evidence one way or the other about the effects of radiology experience on VWM performance.

Other research has demonstrated a more general expertise effect in visual attention and target detection abilities for radiologists. For example, radiologists are better than novices at detecting low-contrast dots in nonradiograph images (Snowden, Davies, & Roling, 2000). Even though the prior knowledge of experts should have been irrelevant in this task, given the nature of the stimuli, experts nevertheless outperformed novices. This study demonstrated superior perceptual abilities for experts compared with novices for domain-general stimuli, yet it is still unknown whether a general improvement in performance can be found in tasks that require VWM.

In the current study, we examined whether there is a general or specific effect of radiography experience on VWM by examining advanced veterinary medicine students' and veterinarians' performance on change detection tasks consisting of real-world scenes and veterinary radiographs. If a domain-general effect occurs, students and veterinarians with more experience reading radiographs should show better change detection performance with both types of stimuli compared with novices. If a domain-specific effect occurs, higher levels of experience should be associated with better change detection performance for the radiographs than for the real-world scenes.

What Is the Relationship Between Amount of Experience and VWM Performance?

It has been argued that in several domains (e.g., music, chess), a minimum of 10 years or more of intense practice and training is needed to obtain expert-level performance (Simon & Chase, 1973; for a review, see Ericsson et al., 1993). Although obtaining expertise in a given task may require a minimum of 10 years of experience, the manifestation of expertise-level performance can occur within a much shorter period of time (e.g., Gauthier & Tarr, 2002; Green & Bavelier, 2003). Furthermore, in some domains, the amount of experience one has does not always predict one's performance on domain-relevant tasks (see Ericsson, 2004, 2006, for review). In particular, it seems that the type of experience may play an important role in whether performance continues to

improve with experience or not (Ericsson, 2004). In the current study, we are interested in how the level of training and/or amount of experience in reading radiographs affects levels of performance in a VWM task among groups of individuals whose training and experience in the area of examining radiographs spans from novice to nearly 30 years of experience.

It is generally assumed that more training and/or experience in a domain will lead to continued improvement on domain-relevant tasks (Ericsson et al., 1993). However, the initial levels of improvement could be higher than later levels (Miglioretti et al., 2009; Newell & Rosenbloom, 1981), and/or a plateau could be reached and persist while lower-order functions of the task are made more automatic (Bryan & Harter, 1897, 1899). Furthermore, deliberate practice (i.e., sufficient opportunity to practice a specific task with feedback) appears to be needed to show continued improvement throughout levels of experience (Ericsson, 2004). Within the domain of radiology, it has been suggested that the largest changes in the ability to accurately read mammograms occurs within the first few years of experience within the domain (Miglioretti et al., 2009). Performance continues to improve, mainly by fewer false detections, throughout the first 10 years in the profession, but gains are not nearly as strong as they are in the first few years (Miglioretti et al., 2009; Newell & Rosenbloom, 1981). Therefore, it is possible that the amount of experience would be correlated with VWM performance early in training but less so later in a radiologist's career.

It has been proposed that although the largest improvements occur during early years of experience, performance continues to increase with experience as long as the expert continues to be engaged in deliberate practice (Ericsson, 2004, 2006). In support of continued improvements throughout a radiologist's career, Laurent, Ward, Williams, and Ripoll (2006) speculated that as expertise increases, visual knowledge representations gradually change from consisting of weakly linked entities to more highly structured and complete representations. Similarly, Schyns and colleagues (Schyns, Goldstone, & Thibaut, 1998; Schyns & Rodet, 1997) argued that in object recognition, feature learning is a progressive and

flexible process that changes and evolves with experience. This learning process results from the organizing and categorizing of information into new or more informative visual representations given experience. Additionally, Gauthier and Tarr (2002) demonstrated that the acquisition of expertise in face recognition can result in the gradual shift from part-based to object-based processing.

Curran, Gibson, Horne, Young, and Bozell (2009) found that expertise effects on the process of detecting changes, as measured in event-related potentials, positively correlated with years of experience for expert image analysts. These findings from Curran et al., together with the findings from face and object recognition, suggest that VWM performance on a domain-specific task may be correlated with the amount of training and/or experience with a task. A lack of correlation within a range of experience would suggest that these gradual shifts in processing have reached a ceiling or plateau.

It is possible that performance in a given domain is not always positively correlated with amount of experience within the domain. As suggested by Ericsson (2006), after an acceptable level of automated performance has been reached, experts may fail to engage in deliberate practice, causing performance to plateau. Not only may performance not continue to improve with more experience, but there have also been several reported instances in which those with more experience within a domain do not outperform individuals with what would be considered minimal experience (see Ericsson, 2006, for review). There are even instances of practitioners interpreting heart sounds and reading X-rays in which performance declines with higher levels of experience (see Ericsson, 2004, 2006).

The Current Set of Experiments

The current study addresses the following questions: (a) Do radiologists demonstrate domain-specific or domain-general effects on tasks that require VWM, and if so, (b) is performance on the domain-specific task better for individuals with higher levels of experience within the domain of expertise? In the current study, we examine these questions in two experiments involving participants at different

stages of skill acquisition: students being trained to be radiologists and professional radiologists. We examined VWM performance using visual change detection tasks considered to be sensitive to the properties of VWM (Luck & Hollingworth, 2008). Improvements in VWM performance, as measured by a visual change detection task, will likely be related to more efficient organization of information in VWM and better retrieval from LTM (Beck, Peterson, & Angelone, 2007; Beck & van Lamsweerde, 2011). Therefore, although we will refer to VWM performance, it is important to keep in mind that the cause of better VWM performance on a domain-specific change detection task is likely attributable to the use of LTM to store more efficient representations in VWM.

In Experiment 1, veterinary medicine students with varying levels of radiological training and novice undergraduate students performed a one-shot change detection task consisting of veterinary radiographs (domain specific) and real-world scenes (domain general). In Experiment 2, the same images were used in a flicker change detection task administered to veterinarians (doctors of veterinary medicine), novice faculty (PhD faculty members in various disciplines), and novice undergraduate students. If training and experience reading radiographs results in a general improvement in the efficiency of VWM, then veterinarians should have better change detection performance for both the domain-specific and domain-general stimuli (Experiment 2). If there is a specific-expertise effect, veterinarians should perform better on the radiographs than they perform on the real-world images (Experiments 1 and 2). We also measured amount of experience for the veterinarians (years practicing and number of hours per week reading radiographs) to examine whether performance continues to improve with increasing levels of experience. If it does, veterinarians with more experience should also have higher levels of performance on the visual change detection task (Experiment 2).

EXPERIMENT 1

Method

Participants. We recruited 42 undergraduate students and 80 veterinary medicine students

from Louisiana State University to participate in this experiment. The undergraduates received course credit for participation. The veterinary medicine students received \$5 and were entered into a drawing to win an iPod Shuffle.

The participants were classified into one of five groups depending on their level of experience in reading radiographs. All undergraduates had no experience reading radiographs and were classified as Group 0 ($n = 41$). This group included 32 females and 9 males with a mean age of 19.8 years ($SD = 1.85$, range = 18 to 26). Veterinary medicine students with no experience with or classes on reading radiographs were classified as Group 1 ($n = 21$) and included 14 females and 7 males with a mean age of 24.2 years ($SD = 4.7$, range = 20 to 43). Veterinary medicine students who had dealt with radiographs only in a classroom setting, including an Introduction to Radiology course and other courses that used radiographs as supplements but did not involve actually reading radiographs, were classified as Group 2 ($n = 19$). This group included 14 females and 5 males with a mean age of 25.6 years ($SD = 5.6$, range = 22 to 47).

Veterinary medicine students who had taken the same classes as Group 2, but also had experience in viewing and interpreting radiographs for diagnostic purposes, were classified as Group 3 ($n = 18$) and included 11 females and 7 males with a mean age of 26.6 years ($SD = 5.4$, range = 20 to 44). The final group (Group 4; $n = 22$) consisted of veterinary medicine students who, in addition to the class work of Groups 2 and 3, had completed a 4-week rotation through the radiology clinic and included 20 females and 2 males with a mean age of 28.2 years ($SD = 4.6$, range = 24 to 42). All of the participants reported having normal or corrected-to-normal vision.

From this sample, the most experienced students (Group 4) are the 4th-year veterinary students. This group of veterinary students spends a concentrated period of 4 weeks learning radiology. This period includes 2 hr a day of intense one-on-one training with a radiologist. For the rest of the day (approximately 4 hr), students independently read radiographs from teaching files and then check their interpretations against

an answer key. They spend the rest of their day (approximately 2 hr) reviewing radiographs with a radiologist. For the rest of this 4th year, these students have intermittent contact with radiologists to review radiographs while these students are on other rotations (e.g., medicine, surgery). Most animals get radiographs taken in the veterinary school, so 4th-year students have a lot of interaction throughout the year with the radiologists, examining X-rays. Typically, two to three animals a week have a radiograph taken per student, and these students examine these radiographs with the assigned radiologist. Throughout the remainder of the article, this 4th-year training will be referred to as “eyes-on” training.

Materials. We administered a questionnaire to each participant to assess the specific level of expertise in diagnostic radiography based on experiences within the domain. In addition to providing basic information, such as age, gender, eyesight correction, and year in school, participants were asked to describe any experience in interpreting radiographs, whether veterinary, medical, or dental, and to estimate the length of time involved in those experiences. The veterinary medicine participants were also asked to list radiology course work and outside experiences using radiographs, including a short description and approximate hours per week.

This experiment was completed with the use of Superlab 4 to present the stimuli and record the data. Undergraduates completed the experiment on iMac computers with a 2.0 GHz Intel Core Duo 2 processor with a 20-in. glossy widescreen TFT active-matrix liquid crystal display set to a resolution of 1,680 × 1,050 pixels. Veterinary medicine students completed the experiment on an Apple MacBook laptop computer with a 2.1 GHz Intel Core Duo 2 processor with a 13.3-in. glossy widescreen TFT display set to a resolution of 1,280 × 800 pixels.

The radiograph images used in the domain-specific change detection task were modified veterinary digital radiographs provided by the Louisiana State University School of Veterinary Medicine. The total set of radiograph stimuli included 15 prechange images and 15 postchange images (see Figure 1 for an example of

pre- and postchange images). Of these, 14 were used for the radiograph experimental trials, and the remaining was used for a practice trial. Each of these 15 sets of images included pre- and posttreatment radiographic examinations of veterinary patients. All of the changes displayed in the postchange images were diagnostically significant, including both hard and soft tissue abnormalities occurring in both the torso and appendage areas. These images were modified with the use of Adobe Photoshop 2.0 software to cut out the specific diagnostic change from one image and paste it into the corresponding image. This technique minimized extraneous visual changes caused by imaging variations from the pre- and posttreatment images. Of the 15 sets of images, 8 sets displayed horizontal images that were sized to 800 × 600 pixels (744 × 552 pixels on the laptop), and 7 sets displayed vertical images that were sized to 600 × 800 pixels (552 × 744 pixels on the laptop). Viewing distance was not constrained.

The real-world images used in the domain-general change detection task were digital photographs of real-world scenes (e.g., living room scenes, park scenes, café scenes) from Angelone and Severino (2008). The total set of real-world stimuli included 15 prechange images and 15 postchange images (see Figure 1 for an example of pre- and postchange images). Of these, 14 were used for the real-world experimental trials, and the remaining was used for a practice trial. The types of changes included in this experiment were object appearances and disappearances, location changes, and shape changes. The types of changes that occurred for domain-specific and domain-general stimuli were similar. There were three different types of changes: (a) location changes, (b) additions or deletions, and (c) state or identity changes. In the 14 changes used for the radiograph experimental trials, there were three location changes (e.g., a leg bone changes position), four additions or deletions (e.g., white mass in the abdomen is deleted), and seven state or identity changes (fracture in a bone heals). In the 14 changes used for the real-world experimental trials, there were three location changes (e.g., a candle holder changes position on a table), five additions or deletions (e.g., a shoe disappears), and

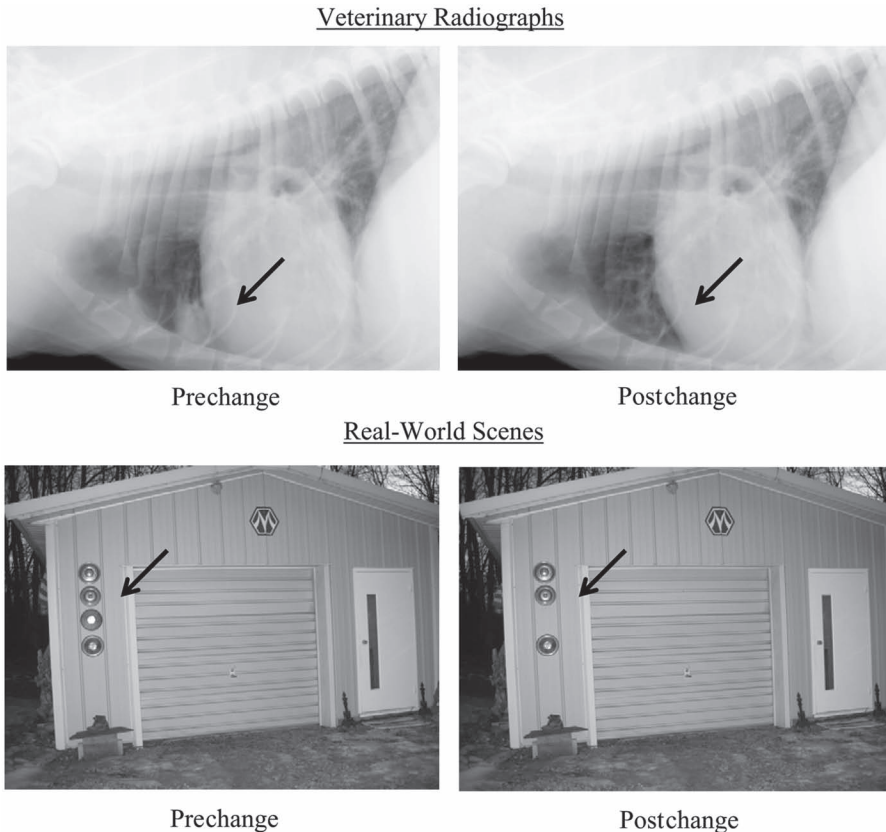


Figure 1. Example of veterinary radiographs and real-world images used in the change detection tasks. Included are examples of prechange and postchange images. Black arrows have been added to point out the location of the change and were not included in the images used in the experiments.

six state or identity changes (e.g., a guitar changes into another guitar of the same type but different size). All images were presented in grayscale.

Procedure. Each participant completed a total of 30 trials during the experiment, with 1 practice trial and 14 experimental trials in the radiograph change detection task (domain-specific task) and 1 practice trial and 14 experimental trials in the real-world change detection task (domain-general task). Trials were blocked by type of change detection task, and the order in which the participants performed each block was counterbalanced. During each trial, the prechange image was displayed for 4,000 ms, followed by a white screen interstimulus interval (ISI) of 800 ms. After the ISI, either the same image (no-change trials) or the postchange

image (change trials) was displayed for 4,000 ms. At the end of the trial, a response screen was displayed asking the participant to indicate whether a change occurred by pressing a particular key on the keyboard: 1 for “yes; a change occurred” or 2 for “no; a change did not occur” (see Figure 2). After the response, another screen appeared asking the participant to press a key to begin the next trial.

At the start of each block, participants were given instructions describing the procedure of the task, followed by two practice trials. The practice trials consisted of a no-change trial and a change trial that used the same prechange image so that the difference between the two types of trials would be clear to the participant. After completion of the practice trials, the experimental trials began. Of the 14 trials in

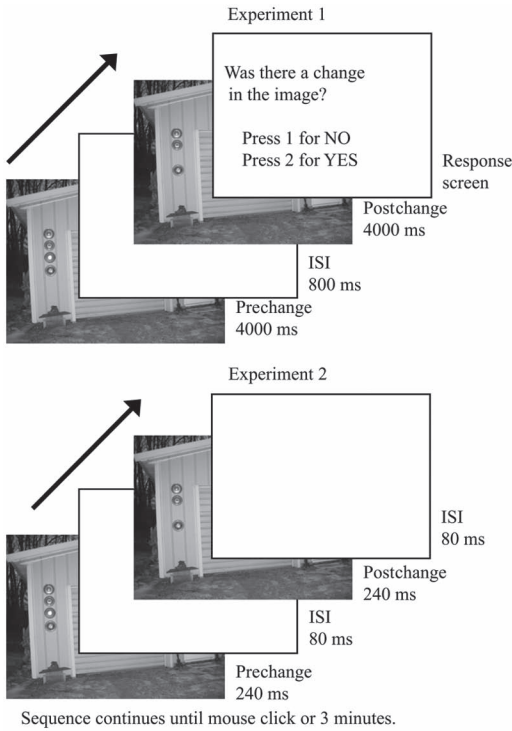


Figure 2. The sequence of events in a change trial in Experiment 1 is shown on the top. Trials end when a response is given for the response screen. The sequence of events on a trial in Experiment 2 is shown on the bottom. Trials end when a mouse click is given on any screen or when 3 min have elapsed.

each block, 7 no-change trials and 7 change trials were presented to participants in a random order. Therefore, within each task, participants viewed 14 prechange images. Half of these were paired with no-change images (same as the prechange image), and half were paired with postchange images. The specific set of images that served as change trials was counterbalanced across participants.

Results

The results (see Table 1) are presented in terms of the nonparametric signal detection measures of A' (Grier, 1971) for change detection sensitivity and B''_D (Donaldson, 1992) for the level of response bias. Chance-level detection sensitivity results in an A' value of 0.5. For response bias, a negative value for B''_D represents a liberal bias

TABLE 1: Means of A' and B''_D by Group and Trial Type for Experiment 1

Level of Expertise	Trial Type	
	Real World	Radiograph
Group 0		
A'	.546 (.014)	.533 (.01)
B''_D	.58 (.055)	.681 (.542)
Group 1		
A'	.547 (.008)	.589 (.024)
B''_D	.369 (.12)	.373 (.107)
Group 2		
A'	.536 (.015)	.560 (.020)
B''_D	.288 (.123)	.354 (.114)
Group 3		
A'	.545(.017)	.559 (.017)
B''_D	.388 (.134)	.393 (.124)
Group 4		
A'	.542 (.009)	.604 (.016)
B''_D	.487 (.106)	.106 (.108)

Note. Values in parentheses represent the standard error of the mean.

(i.e., a bias to make a *change* judgment), and a positive value represents a conservative bias (i.e., a bias to make a *no-change* judgment).

We conducted planned comparisons to test for domain-specific effects. Specifically, for each group, performance on the radiographs was compared with performance on the real-world scenes. Group 4 was the only group to show higher sensitivity for the radiographs than for the real-world scenes, $t(21) = 3.12, p = .005, d = .86$.

A domain-general effect would be revealed by more accurate performance in groups with more advanced training regardless of the type of trial. However, there were not clear predictions about what level of training would result in a domain-general effect. Therefore, we tested for a main effect of group in a 5 (group) \times 2 (trial type) \times 2 (block order: radiograph block first vs. real-world scene block first) mixed-model ANOVA. There was no significant main effect of group, $F(1, 111) = 2.28, MSE = .01, p = .07, \eta^2_p = .08$, demonstrating that there was no domain-general effect.

Predictions about the effects of group on bias were not obvious on the basis of previous research. Therefore, a 5 (group) \times 2 (trial type) \times 2 (block order: radiograph block first vs. real-world scene block first) mixed-model ANOVA was conducted for B''_D . A main effect was found for group, $F(1, 111) = 3.44$, $MSE = .99$, $p = .01$, $\eta^2_p = .56$, and a Group \times Order interaction, $F(4, 111) = 2.51$, $MSE = .73$, $p = .046$, $\eta^2_p = .08$. Using a Bonferroni adjustment for multiple post hoc comparisons, the only significant difference in bias across groups was that Group 0 was more conservative than Group 2.

Discussion

Overall, the results suggest that only the 4th-year veterinary students who had completed the radiology rotation as part of their training showed a domain-specific expertise effect whereby change detection sensitivity for radiographs was higher than for real-world scenes. Furthermore, the lack of a main effect of group shows that increased levels of experience did not lead to a domain-general effect. Additionally, across levels of experience, veterinary students showed no differences in response bias, although Group 0 was more conservative than Group 2. All groups showed sensitivity on both types of changes that was higher than chance (all $ps > .05$), although sensitivity was low overall (overall mean = .56). In addition, all groups showed a conservative response bias for both types of changes. These results suggest that a domain-specific effect in which sensitivity to changes in radiographs is higher than sensitivity to changes in real-world scenes does not appear until veterinary students have participated in the 4-week radiology rotation as part of their veterinary medicine training. In Experiment 2, we further examine the influence of eyes-on training by using a group of participants with more eyes-on experience than 4th-year veterinary students, practicing radiologists.

Although in Experiment 1, the 4th-year veterinary students demonstrated a domain-specific effect, sensitivity on the radiographs was still rather low ($A' = .6$). Therefore, it is possible that more training is needed to show increased levels of sensitivity and/or that the one-shot change detection task used in Experiment 1 was

not sensitive enough for us to detect increased levels of sensitivity. In Experiment 2, we examined the expertise effect using a flicker change detection task, which provides a dependent measure (reaction time) that is potentially more sensitive than the measure for the one-shot change detection task (accuracy). The flicker task has been shown to require VWM processes and is sensitive to the accumulation of information in memory (e.g., Pringle, Kramer, & Irwin, 2004; Rensink, O'Regan, & Clark, 1997; Vierck & Kiesel, 2008). Participants in Experiment 2 consisted of veterinarians, novice faculty members holding a PhD, and novice undergraduate students. Veterinarians' performance was compared with that of two novice groups: undergraduates and PhD university faculty without radiology training. This second novice group served as an age- and education-matched control group. Therefore, this second novice group had acquired expertise in an area other than radiology.

In Experiment 2, we further test for a domain-specific effect for participants with experience with reading radiographs. Specifically, we predict that veterinarians will be faster at detecting changes in the radiographs than in the real-world scenes but that novice faculty members and undergraduates will show no difference in reaction time between the two types of trials or will be faster on the real-world scenes. In addition, in Experiment 2, we examine the relationship between the amount of experience veterinarians have with reading radiographs and their performance on the change detection task. If VWM efficiency continues to improve as more experience is acquired, then there should be a positive correlation between amount of experience and performance on the domain-specific change detection task.

EXPERIMENT 2

Method

Participants. For the second experiment, 19 faculty members from the Louisiana State University School of Veterinary Medicine (expert faculty members) volunteered their participation. The 19 veterinary faculty members included 11 females and 8 males with a mean age of 35.4 years ($SD = 8.95$, range = 25 to 50).

All veterinary faculty members rated themselves as having expert knowledge with reading radiographs. The average number of years working as a veterinarian was 10.05 ($SD = 7.9$, range = 1 to 26 years), and the average number of hours spent reading radiographs per week was 14.63 ($SD = 19.1$, range = 1 to 60 hr). In addition, 18 Louisiana State University faculty members (novice faculty members) from the departments of psychology, sociology, communication studies, physics, and mathematics volunteered their participation. These novice faculty members included 9 females and 9 males with a mean age of 39.7 years ($SD = 9.3$, range = 29 to 60). These novice faculty participants rated themselves as novices with reading radiographs. The average number of years working in their profession was 14.9 years ($SD = 8.2$, range = 1 to 30). Also, 24 Louisiana State University undergraduate students (novice undergraduates) participated in exchange for course credit. The novice undergraduates consisted of 21 females and 3 males with a mean age of 20.1 years ($SD = 1.8$, range = 18 to 24). All undergraduate participants rated themselves as novices with reading radiographs. All participants reported having normal or corrected-to-normal vision.

Materials. The stimuli were presented with the use of Super Lab 4.0 software on an Apple MacBook computer with a 2.1 GHz Intel Core 2 Duo processor and a 13.3-in. glossy widescreen TFT liquid crystal display. The resolution was set to $1,280 \times 800$ pixels. Participants responded using a separate USB-connected mouse.

We created 15 flicker films of radiograph changes using the pre- and postchange images from Experiment 1. We created the flicker films by alternately presenting the pre- and postchange images, separated by a white screen. Each presentation of the pre- and postchange images occurred for 240 ms with an 80-ms ISI (white screen) separating the pre- and postchange images (see Figure 2). Of the 15 flicker films, 8 were displayed horizontally at a size of 12.4 cm in height and 11.9 cm in width (744×552 pixels), and 7 were displayed vertically at a size of 10.7 cm in height and 15.9 cm in width (552×744 pixels). We created 15 real-world flicker films in the same manner as the radiograph

flicker films using the real-world scenes from Experiment 1. Each real-world flicker film was displayed horizontally at a size of 10.7 cm in height and 15.9 cm in width (744×552 pixels). Viewing distance was not constrained.

Procedure. Participants viewed a total of 30 flicker films: 15 radiograph flicker films and 15 real-world flicker films. All films contained a change. Participants were instructed to use the mouse to click as quickly and accurately as possible on the area where the change was occurring in the flicker film. Trial type (i.e., radiograph or real-world scene) was blocked and presentation order was counterbalanced. The order of the trials in each block was random. At the beginning of each block, participants were given instructions corresponding to the type of flicker film to be presented. Participants then completed one practice trial to achieve full understanding of the procedure. After the practice trial, participants confirmed their understanding of the task and began the 14 experimental trials. After each response to the change in the flicker film, participants were asked to press a key to advance to the next trial. Participants were allowed up to 3 min to make a response before each trial timed out.

All participants completed the experiment individually. After completion of the experiment, participants were asked for demographic information (i.e., age and gender), presence of any visual impairments, and level of expertise with reading radiographs. Expert radiology and novice faculty members were also asked for the number of years they have been at their profession and the number of hours per week spent examining radiographs.

Results

The results are discussed in terms of both change detection accuracy and reaction time to the identification of a change. It was expected that accuracy would be fairly high, given that participants had sufficient time (3 min) to find the changes regardless of level of expertise or type of change. Therefore, although accuracy is reported, the critical dependent measure is how quickly the change was detected (reaction time), not whether the change was detected (accuracy). Specifically, veterinarians should

TABLE 2: Correlations Between Change Detection Accuracy (Proportion Correct) and Reaction Time in Experiment 2

Group	Real-World Scene	Radiographs
Novice undergraduates	.21	.25
Novice faculty	.46	.25
Veterinarians	.34	.48

be faster at detecting changes in radiographs compared with undergraduates and novice faculty members. It is important to note that accuracy was positively correlated with reaction time (see Table 2), suggesting that there was not a speed–accuracy trade-off.

Domain-specific and domain-general effects: Accuracy. Participants' accuracy was measured by the proportion of trials in which a mouse click occurred within the change area (a rectangular area encompassing the total area that differed between the pre- and postchange images). Trials were inaccurate if no mouse click occurred (less than 1% of the inaccurate trials) or if the mouse-click location was not on the change region (more than 99% of the inaccurate trials). To test for the possibility of a domain-specific effect, planned comparisons were conducted between accuracy for the domain-specific and domain-general trials for each group. Novice undergraduates were more accurate for the real-world trials ($M = .90$, $SE = .03$) than for the radiograph trials ($M = .74$, $SE = .04$), $t(23) = 4.52$, $p < .001$, $d = 1.04$ (see Figure 3). Novice faculty were also more accurate for the real-world trials ($M = .93$, $SE = .02$) than for radiograph trials ($M = .79$, $SE = .03$), $t(17) = 4.96$, $p < .001$, $d = 1.15$, whereas the veterinary faculty were equally accurate for radiograph ($M = .96$, $SE = .01$) and real-world ($M = .94$, $SE = .01$) trials, $t(18) = 1.23$, $p = .24$, $d = .38$. See Figure 3.

A domain-general effect would be revealed if veterinarians were more accurate than novice faculty and novice undergraduates regardless of the type of trial. This effect was tested with planned comparisons between groups for each type of trial. Veterinarians were more accurate than the novice undergraduates, $t(41) = 5.38$, $p < .001$, $d = 1.68$, and the novice faculty,

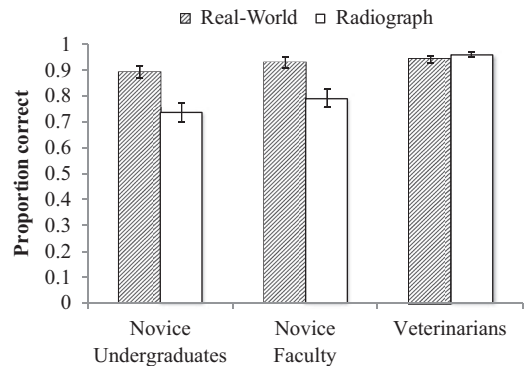


Figure 3. Experiment 2 accuracy (proportion correct) for domain-general (real-world) and domain-specific (radiograph) flicker change detection tasks at each level of expertise. Error bars represent standard error of the mean.

$t(35) = 4.86$, $p < .001$, $d = 1.64$, on the radiograph trials but not on the real-world trials: veterinarians versus undergraduates, $t(41) = 1.57$, $p = .13$, $d = .49$; veterinarians versus novice faculty, $t(35) = .44$, $p = .66$, $d = .15$. The results demonstrate that there was not a domain-general effect.

Domain-specific and domain-general effects: Reaction times. Participants' reaction times were measured as the time between the onset of the first stimulus in the flicker movie and when a mouse-click response was given. Only trials in which the mouse click occurred within the change region (accurate trials) were included in the reaction time analysis. To test for the possibility of a domain-specific effect, planned comparisons were conducted between reaction times for the domain-specific and domain-general trials for each group. Novice undergraduates detected changes in the real-world trials ($M = 6,521$ ms, $SE = 387$) at a similar speed as

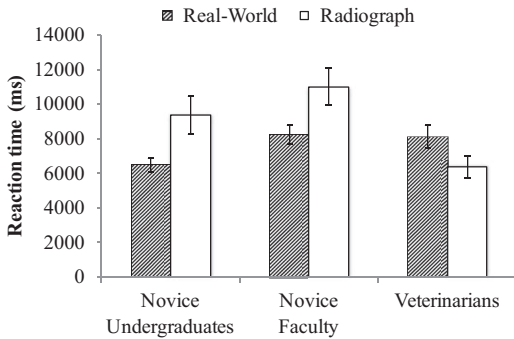


Figure 4. Experiment 2 reaction times (in milliseconds) for accurate identification of changes for domain-general (real-world) and domain-specific (radiograph) flicker change detection tasks at each level of expertise. Error bars represent standard error of the mean.

they detected changes in the radiograph trials ($M = 9,405$ ms, $SE = 1,107$), $t(23) = 2.61$, $p = .016$, $d = .71$ (see Figure 4). Novice faculty were faster for the real-world trials ($M = 8,267$ ms, $SE = 544$) than for the radiograph trials ($M = 11,056$ ms, $SE = 1,090$), $t(17) = 3.32$, $p = .0041$, $d = .76$. The veterinarians' pattern of reaction times was in the opposite direction, with faster reaction times on the radiograph trials ($M = 6,389$ ms, $SE = 630$) compared with the real-world trials ($M = 8,166$ ms, $SE = 682$), $t(18) = 2.17$, $p = .04$, $d = .62$.

If there is a domain-general effect, then veterinary faculty will be faster overall, regardless of the type of trial. Planned comparisons revealed that veterinary faculty were faster than novice faculty, $t(35) = 3.76$, $p < .001$, $d = 1.27$, and novice undergraduates, $t(41) = 2.21$, $p = .03$, $d = .7$, on the radiograph trials. However, on the real-world trials, the veterinary faculty were not faster than novice faculty, $t(35) = .12$, $p = .91$, $d = .04$, and were slower than the novice undergraduates, $t(41) = -2.2$, $p = .03$, $d = .66$. Therefore, there was not a domain-general effect.

The effect of experience within the veterinary faculty group. We were also interested in determining the relationship between the amount of experience the veterinary faculty had with reading radiographs and their performance on the domain-specific change detection trials. To assess this relationship, we conducted bivariate

correlations on the number of years the veterinary faculty members had been practicing veterinary medicine, the number of hours per week they reported examining radiographs, and the accuracy and reaction times of detecting changes on the domain-specific trials (see Table 3). No significant correlations were found. Considering that the age of the veterinary faculty may potentially be influencing the correlations between amount of experience with examining radiographs and task performance, we conducted partial correlations controlling for age in the analyses. Again, no significant correlations were found.

Correlations were also conducted on the domain-specific effect and the amount of experience the expert faculty had with reading radiographs. We calculated the domain-specific effect by subtracting veterinary faculty members' accuracy and reaction times on the radiograph change detection trials from their accuracy and reaction times on the real-world change detection trials, respectively. Once again, we found no significant correlations, even when controlling for age (see Table 3).

Discussion

As observed in Experiment 1, a domain-specific effect was found whereby veterinary faculty detected changes to radiographs more accurately and faster than they detected changes to real-world scenes. In addition, veterinary faculty performed better than novice faculty and undergraduates on radiograph trials but not on real-world trials. Therefore, there was domain-specific effect but not a domain-general effect. Experiment 2 also provided no evidence of higher levels of performance for veterinarians with more experience. This finding is supported by the lack of a relationship between change detection performance and amount of experience with reading radiographs.

We were unable to measure bias in Experiment 2 as we did in Experiment 1 because all trials contained a change. However, as was found in Experiment 1, the faster reaction times for novice undergraduates suggest that they may have had a more liberal response bias, and the slower reaction times for novice faculty members suggest that they may have had a

TABLE 3: Correlations Between Change Detection Performance and Amount of Experience With Radiographs for the Veterinary Medicine Faculty in Experiment 2

Change Detection Performance	Experience Measure	
	Years Practicing	Hours per Week
Domain-specific performance		
Accuracy	-.21 (.40)	.04 (.86)
Reaction time	.15 (.55)	-.12 (.63)
Domain-specific performance controlling for age		
Accuracy	-.34 (.16)	.02 (.93)
Reaction time	-.03 (.92)	-.08 (.74)
Domain-specific effects		
Accuracy	-.25 (.31)	.02 (.95)
Reaction time	-.06 (.81)	-.08 (.76)
Domain-specific effects controlling for age		
Accuracy	.05 (.86)	-.05 (.85)
Reaction time	.30 (.23)	-.13 (.62)

Note. Values in parentheses represent the *p* value. Domain-specific effects = domain-specific performance – domain-general performance.

more conservative response bias. However, the high levels of accuracy and the positive correlations between reaction time and accuracy (see Table 2) indicate that the faster reaction times for undergraduates were largely driven by finding the change quickly rather than simply responding quickly without knowing where the change was located.

GENERAL DISCUSSION

The patterns of results from these experiments suggest that the effects of radiology experience observed in a VWM task are (a) limited to stimuli specific to radiology, (b) are evident only after eyes-on training, and (c) do not change across veterinary faculty with varying levels of experience in radiology. In Experiment 1, only the most senior veterinary medicine students who had completed a 4-week radiological rotation demonstrated a domain-specific effect by showing greater detection sensitivity for domain-specific stimuli than for domain-general stimuli. In Experiment 2, veterinary faculty demonstrated a domain-specific effect, and the size of this effect was similar regardless of the amount of radiograph experience reported by the veterinary faculty. Together,

these findings demonstrate that the effect of experience is domain specific and is present during the first few years of experience, after which a plateau is reached.

The findings from the current study suggest that the expertise benefit in performance on a VWM task is limited to visual stimuli relevant to the area of expertise. In other words, our findings argue for a domain-specific interpretation of VWM performance, given radiological experience. These results support research in which experts show improved performance on domain-specific tasks because they may have more efficient visual attention allocation (e.g., Christensen et al., 1981; Jarodzka et al., 2010; Werner & Thies, 2000), have more highly structured or enhanced LTM representations (e.g., Boshuizen & Schmidt, 1992; Freyhof, Gruber, & Ziegler, 1992; Gobet & Simon, 1998; Medin, Lynch, Coley, & Atran, 1997; Werner & Thies, 2000), or use more holistic perceptual organization to enhance the capacity or the resolution of VWM (e.g., Curby & Gauthier, 2007; Curby, Glazek, & Gauthier, 2009; Scolar, Vogel, & Awh, 2008). The current study supports these findings for the area of radiology expertise, whereby radiologists performed better with

domain-specific stimuli than with real-world stimuli in change detection tasks. This presence of a domain-specific effect and no domain-general effect suggests that LTM knowledge specific to the field of radiology is being used to direct VWM recourses more accurately and efficiently rather than an overarching strategy that can be applied to any type of stimuli regardless of relevance to the area of expertise.

Only those participants who had eyes-on experience with reading veterinary radiographs demonstrated domain-specific effects. In Experiment 1, veterinary medicine students who had completed a 4-week radiology rotation showed domain-specific effects, whereas all the other groups of participants showed equal performance on the domain-specific and domain-general tasks. In Experiment 2, veterinarians showed a domain-specific effect, but no significant relationships were found between the number of years spent practicing veterinary medicine and the size of the domain-specific effect or between the reported hours per week spent reading radiographs and the size of the domain-specific effect. These results appear to go against the hypothesis that performance will continue to improve with higher levels of experience. Additionally, the lack of significant correlations between performance on the domain-specific task and years of experience or hours spent reading radiographs for the veterinary faculty in Experiment 2 does not fall in line with the findings from Curran et al. (2009) showing that amplitudes of event-related potentials increased with years of experience for expert-level image analysts.

Our results need to be considered in light of the following. First, the current study was cross-sectional in design, so we cannot rule out the possibility that cohort effects attenuated the correlations in Experiment 2 in some manner. Second, all of the veterinary faculty, although they rated themselves as experts, may not be considered experts by the requirements of the literature (Hoffman, 1998). The majority of the veterinary faculty did not meet the 10-year rule used by some groups to define expertise (Simon & Chase, 1973); 13 of the 19 veterinary faculty reported being in their profession for fewer than 10 years. Therefore, in contrast to the 10-year

rule for expertise (Simon & Chase, 1973; for a review, see Ericsson et al., 1993), a domain-specific expertise effect occurred for individuals with fewer than 10 years of experience, and a plateau in performance was reached prior to 10 years of experience. However, the current study leaves open the possibility that a larger domain-specific expertise effect may be found with a sample containing more individuals with more than 10 years of experience.

Finally, veterinary medicine students were not directly compared with veterinary faculty on the same type of change detection task, although the same stimuli were used. Therefore, it is possible that domain-specific effects may have been found in Experiment 1 for Groups 0 through 3 if the more sensitive measure of reaction time was used. Despite these potential limitations, our findings are in line with previous research (Miglioretti et al., 2009) that suggests that experience leads to an early improvement in performance, which then plateaus as more experience is accumulated.

These results lead to several recommendations for training veterinary and medical students to become experts at reading radiographs. First, eyes-on training appears to be important for improving change detection performance with radiographs. In Experiment 1, even though students in Groups 1 through 3 had received instruction on anatomy and on radiographs, this knowledge was not applied to the task of detecting changes in radiographs until the radiology rotation was completed. This finding suggests that the knowledge itself is not sufficient; application of this knowledge to domain-specific stimuli is needed to develop better VWM performance (Snowden et al., 2000). Furthermore, the current results suggest that training on radiographs may not lead to improved performance on new, non-radiograph-related VWM tasks radiologists must learn to perform. That is, developing expertise in reading radiographs does not lead to expertise in other VWM tasks, such as detecting changes in charts depicting patients' vitals pre- and posttreatment.

Overall, the findings from this study suggest that extensive and concentrated training in reading and interpreting radiographs is required for domain-specific effects to be evident in VWM

abilities. Furthermore, when this eyes-on training has led to a domain-specific effect, further training and experience is not necessarily associated with better performance. This finding provides an important step toward further understanding the specificity of these expertise effects and their relationship with the amount of experience within the domain of expertise.

KEY POINTS

- Training and experience reading radiographs leads to a domain-specific effect on visual working memory performance.
- Veterinary students who had completed a radiology rotation, showed improved visual working memory performance for domain-specific stimuli compared with domain-general stimuli.
- The performance benefit afforded by being a radiology professional does not increase as a function of greater amounts of experience or frequency in reading and interpreting radiographs.

REFERENCES

- Alvarez, G. A., & Cavanagh, P. (2004). The capacity of visual short-term memory is set both by visual information load and by number of objects. *Psychological Science*, *15*, 106–111. doi:10.1111/j.0963-7214.2004.01502006.x
- Angelone, B., & Severino, S. (2008, May). *Effects of individual differences on the ability to detect changes in natural scenes*. Poster presented at the annual meeting of the Vision Sciences Society, Naples, FL.
- Bass, J. C., & Chiles, C. (1990). Visual skill correlation with detection of solitary pulmonary nodules. *Investigative Radiology*, *25*, 994–998.
- Beck, M. R., Peterson, M. S., & Angelone, B. A. (2007). The roles of encoding, retrieval, and awareness in change detection. *Memory and Cognition*, *35*, 610–620.
- Beck, M. R., & van Lamsweerde, A. E. (2011). Accessing long-term memory representations during visual change detection. *Memory and Cognition*, *39*, 433–446. doi:10.3758/s13421-010-0033-4
- Boshuizen, H. P. A., & Schmidt, H. G. (1992). On the role of biomedical knowledge in clinical reasoning by experts, intermediates and novices. *Cognitive Science*, *16*, 153–184.
- Bryan, W. L., & Harter, N. (1897). Studies in the physiology and psychology of the telegraphic language. *Psychological Review*, *4*, 27–53.
- Bryan, W. L., & Harter, N. (1899). Studies on the telegraphic language: The acquisition of a hierarchy of habits. *Psychology Review*, *6*, 345–375.
- Chase, W. G., & Ericsson, K. A. (1981). Skilled memory. In J. R. Anderson (Ed.), *Cognitive skills and their acquisition* (pp. 141–189). Hillsdale, NJ: Lawrence Erlbaum.
- Chase, W. G., & Simon, H. A. (1973a). The mind's eye in chess. In W. G. Chase (Ed.), *Visual information processing* (pp. 215–281). San Diego, CA: Academic Press.
- Chase, W. G., & Simon, H. A. (1973b). Perception in chess. *Cognitive Psychology*, *4*, 55–81.
- Charness, N. (1976). Memory for chess positions: Resistance to interference. *Journal of Experimental Psychology: Human Learning and Memory*, *2*, 641–653.
- Christensen, E. E., Murry, R. C., Holland, K., Reynolds, J., Landay, M. J., & Moore, J. G. (1981). The effect of search time on perception. *Diagnostic Radiology*, *138*, 361–365.
- Curby, K. M., & Gauthier, I. (2007). A visual short-term memory advantage for faces. *Psychonomic Bulletin & Review*, *14*, 620–628.
- Curby, K. M., Glazek, K., & Gauthier, I. (2009). A visual short-term memory advantage for objects of expertise. *Journal of Experimental Psychology: Human Perception and Performance*, *35*, 94–107. doi:10.1037/0096-1523.35.1.94
- Curran, T., Gibson, L., Horne, J. H., Young, B., & Bozell, A. P. (2009). Expert image analysts show enhanced visual processing in change detection. *Psychonomic Bulletin & Review*, *16*, 390–397. doi:10.3758/PBR.16.2.390
- Donaldson, W. (1992). Measuring recognition memory. *Journal of Experimental Psychology: General*, *121*, 275–277.
- Eng, H. Y., Chen, D., & Jiang, Y. (2005). Visual working memory for simple and complex visual stimuli. *Psychonomic Bulletin & Review*, *12*, 1127–1133.
- Ericsson, K. A. (2004). Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. *Academic Medicine*, *79*, S70–S81.
- Ericsson, K. A. (2006). The influence of experience and deliberate practice on the development of superior expert performance. In K. A. Ericsson, N. Charness, P. Feltovich, & R. R. Hoffman (Eds.), *Cambridge handbook of expertise and expert performance* (pp. 685–706). Cambridge, UK: Cambridge University Press.
- Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review*, *102*, 211–245.
- Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review*, *100*, 363–406. doi:10.1037/0033-295X.100.3.363
- Ericsson, K. A., & Staszewski, J. J. (1989). Skilled memory and expertise: Mechanisms of exceptional performance. In D. Klahr & K. Kotovsky (Eds.), *Complex information processing: The impact of Herbert A. Simon* (pp. 235–267). Hillsdale, NJ: Lawrence Erlbaum.
- Ferrari, V., Didierjean, A., & Marmèche, E. (2008). Effect of expertise acquisition on strategic perception: The example of chess. *Quarterly Journal of Experimental Psychology*, *61*, 1265–1280. doi:10.1080/17470210701503344
- Freyhof, H., Gruber, H., & Ziegler, A. (1992). Expertise and hierarchical knowledge representation in chess. *Psychological Research*, *54*, 32–37. doi:10.1007/BF01359221
- Gauthier, I., & Tarr, M. J. (2002). Unraveling mechanisms for expert object recognition: Bridging brain activity and behavior. *Journal of Experimental Psychology: Human Perception and Performance*, *28*, 431–446. doi:10.1037/0096-1523.28.2.431
- Gobet, F., & Simon, H. A. (1998). Expert chess memory: Revisiting the chunking hypothesis. *Memory*, *6*, 225–255. doi:10.1080/741942359
- Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature*, *423*, 534–537. doi:10.1038/nature01647
- Green, C. S., & Bavelier, D. (2006). Effect of action video games on the spatial distribution of visuospatial attention. *Journal of Experimental Psychology: Human Perception and Performance*, *32*, 1465–1478. doi:10.1037/0096-1523.32.6.1465

- Grier, J. B. (1971). Nonparametric indexes for sensitivity and bias: Computing formulas. *Psychological Bulletin*, 75, 424–429.
- Hoffman, R. R. (1998). How can expertise be defined? Implications of research from cognitive psychology. In R. Williams, W. Faulkner, & J. Fleck (Eds.), *Exploring expertise* (pp. 81–100). New York, NY: Macmillan.
- Hubet-Wallander, B., Green, C. S., Sugarman, M., & Bavelier, D. (2011). Changes in search rate but not in dynamics of exogenous attention in action videogame players. *Attention Perception and Psychophysics*, 73, 2399–2412. doi:10.3758/s13414-011-0194-7
- Irwin, D. E. (1992). Memory for position and identity across eye movements. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 18, 307–317. doi:10.1037/0278-7393.18.2.307
- Irwin, D. E., & Andrews, R. V. (1996). Integration and accumulation of information across saccadic eye movements. In I. Toshio & J. L. McClelland (Eds.), *Attention and performance 16: Information integration in perception and communication* (pp. 125–155). Cambridge, MA: MIT Press.
- Jarodzka, H., Scheiter, K., Gerjets, P., & van Gog, T. (2010). In the eyes of the beholder: How experts and novices interpret dynamic stimuli. *Learning and Instruction*, 20, 146–154. doi:10.1016/j.learninstruc.2009.02.019
- Laurent, E., Ward, P., Williams, A. M., & Ripoll, H. (2006). Expertise in basketball modifies perceptual discrimination abilities, underlying cognitive processes, and visual behaviours. *Visual Cognition*, 13, 247–271. doi:10.1080/13506280544000020
- Lesgold, A., Rubinson, H., Feltovich, P. J., Glaser, R., Klopfer, D., & Wang, Y. (1988). Expertise in a complex skill: Diagnosing X-ray pictures. In M. T. H. Chi, R. Chaser, & M. Farr (Eds.), *The nature of expertise* (pp. 311–342). Hillsdale, NJ: Lawrence Erlbaum.
- Levin, D. T., Simons, D. J., Angelone, B. L., & Chabris, C. F. (2002). Memory for centrally attended changing objects in an incidental real-world change detection paradigm. *British Journal of Psychology*, 93, 289–302. doi:10.1348/000712602760146224
- Luck, S. J., & Hollingworth, A. (2008). *Visual memory*. New York, NY: Oxford University Press.
- Medin, D. L., Lynch, E. B., Coley, J. D., & Atran, S. (1997). Categorization and reasoning among tree experts: Do all roads lead to Rome? *Cognitive Psychology*, 32, 49–96. doi:10.1006/cogp.1997.0645
- Memmert, D., Simons, D. J., & Grimme, T. (2009). The relationship between visual attention and expertise in sports. *Psychology of Sport and Exercise*, 10, 146–151. doi:10.1016/j.psychsport.2008.06.002
- Miglioretti, D. L., Gard, C. C., Carney, P. A., Onega, T. L., Buist, D. S., Sickles, E. A., Kerlikowske, K., Rosenberg, R. D., Yankaskas, B. C., Geller, B. M., & Elmore, J. (2009). When radiologists perform best: The learning curve in screening mammogram interpretation. *Radiology*, 253, 632–640.
- Myles-Worsley, M., Johnston, W. A., & Simons, M. A. (1988). The influence of expertise on X-ray image processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 14, 553–557. doi:10.1037/0278-7393.14.3.553
- Newell, A., & Rosenbloom, P. S. (1981). Mechanisms of skill acquisition and the law of practice. In J. R. Anderson (Ed.), *Cognitive skills and their acquisition* (pp. 1–55). Hillsdale, NJ: Lawrence Erlbaum.
- Nodine, C. F., & Krupinski, E. A. (1998). Perceptual skill, radiology expertise, and visual test performance with NINA and WALDO. *Academic Radiology*, 5, 603–612.
- O'Regan, J. K. (1992). Solving the “real” mysteries of visual perception: The world as an outside memory. *Canadian Journal of Psychology*, 46, 461–488. doi:10.1037/h0084327
- Pringle, H. L., Kramer, A. F., & Irwin, D. E. (2004). Individual differences in the visual representation of scenes. In D. T. Levin (Ed.), *Thinking and seeing: Visual metacognition in adults and children* (pp. 165–185). Cambridge, MA: MIT Press.
- Reingold, E. M., Charness, N., Pomplun, M., & Stampe, D. M. (2001). Visual span in expert chess players: Evidence from eye movements. *Psychological Science*, 12, 48–55. doi:10.1111/1467-9280.00309
- Rensink, R. A. (2000). Visual search for change: A probe into the nature of attentional processing. *Visual Cognition*, 7, 345–376. doi:10.1080/135062800394847
- Rensink, R. A., O'Regan, K., & Clark, J. J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science*, 8, 368–373. doi:10.1111/j.1467-9280.1997.tb00427.x
- Schyns, P. G., Goldstone, R. L., & Thibaut, J. (1998). The development of features in object concepts. *Behavioral and Brain Science*, 21, 1–54. doi:10.1017/S0140525X98000107
- Schyns, P. G., & Rodet, L. (1997). Categorization creates functional features. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 23, 681–696. doi:10.1037/0278-7393.23.3.681
- Scolari, M., Vogel, E. K., & Awh, E. (2008). Perceptual expertise enhances the resolution but not the number of representations in working memory. *Psychonomic Bulletin & Review*, 15, 215–222. doi:10.3758/PBR.15.1.215
- Simon, H. A., & Chase, W. G. (1973). Skill in chess. *American Scientist*, 61, 394–403.
- Simons, D. J. (1996). In sight, out of mind: When object representations fail. *Psychological Science*, 7, 301–305. doi:10.1111/j.1467-9280.1996.tb00378.x
- Simons, D. J., & Levin, D. T. (1997). Change blindness. *Trends in Cognitive Sciences*, 1, 501–506. doi:10.1016/S1364-6613(97)01080-2
- Simons, D. J., & Rensink, R. A. (2005). Change blindness: Past, present, and future. *Trends in Cognitive Sciences*, 9, 16–20. doi:10.1016/j.tics.2004.11.006
- Snowden, P. T., Davies, I. R. L., & Roling, P. (2000). Perceptual learning of the detection of features in X-ray images: A functional role for improvements in adults' visual sensitivity? *Journal of Experimental Psychology: Human Perception and Performance*, 26, 379–390. doi:10.1037/0096-1523.26.1.379
- Vierck, E., & Kiesel, A. (2008). Change detection: Evidence for information accumulation in flicker paradigms. *Acta Psychologica*, 127, 309–323. doi:10.1016/j.actpsy.2007.06.004
- Waters, A. J., Gobet, F., & Leyden, G. (2002). Visuospatial abilities of chess players. *British Journal of Psychology*, 93, 557–565. doi:10.1348/000712602761381402
- Werner, S., & Thies, B. (2000). Is “change blindness” attenuated by domain-specific expertise? An expert-novices comparison of change detection in football images. *Visual Cognition*, 7, 163–173. doi:10.1080/135062800394748

Melissa R. Beck is an associate professor at Louisiana State University. She received a PhD in psychology in 2003 from Kent State University.

Benjamin A. Martin received a PhD in psychology in 2011 from Louisiana State University.

Emily Smitherman is a pediatrics resident at Duke University Medical Center. She received an MD in 2012 from University of Texas Southwestern Medical Center.

Lorrie Gaschen is an associate professor at Louisiana State University. She received a PhD in veterinary radiology in 2001 from University of Utrecht.

Date received: January 3, 2011

Date accepted: October 21, 2012