Digital pathology: the effect of experience on visual search behavior

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Abstract

Purpose: The introduction of whole slide imaging and digital pathology has enabled greater scrutiny of visual search behaviors among pathologists. We aim to investigate zooming and panning behaviors, external markers of visual processing capabilities, and the changes with experience.

Approaches: Twenty digitized breast core needle biopsy histopathology slides were obtained from the circulating slides from the main digital pathology trial (IRAS number: 258799). These were presented to five pathologists with varying experience (1.5 to 40 years) whose examinations were recorded. Data of visual fixations were collected using eye-tracking cameras, and the magnification data and zooming behaviors were extracted in an objective fashion by an automated algorithm. The relationship between experience and metrics was analyzed using mixed-effects regression analyses.

Results: There was a significant association between experience and both reading times ($p < 0.001$) and a number of fixations ($p < 0.001$), with these relationships being inversely proportional. The greater experience was also associated with greater diagnostic accuracy ($p = 0.033$). We found that experience was significantly associated with greater use of magnification changes ($p < 0.001$). Conversely, less experience showed a near significant association with the increased proportion of time spent panning ($p = 0.070$).

Conclusions: Fewer fixations needed to reach a diagnosis and quicker reading times are indicative of greater cognitive and visual processing capabilities with greater experience. These cognitive capabilities may be a prerequisite for the more frequent zooming changes that are more prevalent with increasing experience.

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1 Introduction

The introduction of whole slide imaging (WSI) has the potential to revolutionize the world of surgical cellular pathology. WSI enables the production of high-quality digital copies of histopathology glass slides, which can be stored digitally, seamlessly shared between pathologists, and viewed on any high-resolution computer monitor.[1,2] Therefore, slide viewing and reporting no longer rely on access to a light microscope and the physical glass slides, meaning that the reporting task can be completed remotely and is not restricted to a laboratory.[3] Furthermore,

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unique slides can be rapidly circulated and accessed by numerous pathologists simultaneously, facilitating second opinion discussions and education.[1]

The transition from a light microscope to a digital computer workstation for pathology reporting also permits the use of eye-tracking technologies that can nonintrusively record pathologists' eye movements during the image interpretation task. These eye-tracking data can be used to objectively explore how pathologists engage with digitized microscope slides by revealing visual search and cognitive behavior.[4] Being a specialty that is reliant on visual inspection, it is prudent to understand how these behaviors can contribute to efficient reading techniques and improved diagnostic accuracy, which could be applied in the education and training of pathologists to increase their confidence and performance.[4]

Though eye-tracking studies have been frequently conducted in the field of medical imaging to understand image interpretation tasks, most of these studies have focused on radiology, a field that has been fully digital for over two decades.[5,6] Due to the relative novelty of digital pathology (DP), and the challenges encountered with synchronizing eye gaze data with the highly dynamic digital image (due to essential panning and zooming navigation), digital pathology has not been so thoroughly investigated. Early DP eye-tracking studies by Krupinski et al. (2006, 2013) demonstrated how less experienced pathologists exhibited increased time on task and made more visual fixations than experienced pathologists when comparing trainees against expert pathologists and when comparing residents over a four year training period.[7,8] However, these studies used static digital slides at a low magnification that could not be zoomed or panned. Other studies allowed pathologists to navigate slides freely, but instead of tracking eye movement, tracked only the viewport as a proxy of slide visual coverage and began to investigate image navigation techniques including zoom and panning characteristics.[9–11] Only a limited number of studies have combined eye-tracking and viewport tracking elements to more comprehensively assess pathologist search and reading behavior.[12,13]

As part of an ongoing National Institute for Health and Care Research (NIHR) funded Digital Pathology validation study that aims to evaluate the implementation of WSI technology within the National Health Service (NHS),[14] we have employed eye-tracking technology to investigate pathologists' examination of digital slide images. Full implementation of this new technology in the NHS is anticipated in the near future, and the education of trainee pathologists offers opportunities to facilitate this uptake. We, therefore, aim to build upon the previous research discussed above by investigating the differences in visual search behavior in pathologists of varying levels of experience that could be used to help develop expertise and be used to promote the acquisition of good examination techniques by pathology trainees.

2 Materials and Methods

2.1 *Participants*

Five pathologists from Nottingham University Hospitals NHS Trust, participating in the Digital Pathology Trial, were recruited. The Digital Pathology Trial is a multi-center validation of digital WSI for routine diagnosis, IRAS number: 258799, funded by NIHR, sponsored by University Hospitals Coventry & Warwickshire NHS Trust, with ethics approval from the National Ethics Committee.[14] The participants had a range of experience reporting breast pathology slides, including two pathology trainees and three pathology consultants with varying numbers of years of experience. Some of the participants had no prior digital pathology experience and were provided with online training sessions, information, and video tutorials on how to use the viewing software before data collection. Before commencing the study set of cases, they were allowed to practice using an example set of slides to familiarize themselves with the viewing software.

2.2 *Sample Selection*

Twenty digitized breast core needle biopsy histopathology slides were obtained specimens were used in this study. These specimens were obtained from the circulating slides from the main Digital Pathology Trial, collected from participating sites across the UK.[14] These samples were

selected by an expert, with 20 years of experience in breast pathology, to include a range of diagnoses and difficulties.

The ground truth diagnoses were agreed upon by consensus after the slides had been read by the pathologists in the main study. Diagnostic accuracy was measured by comparing the diagnoses proffered with the ground truth diagnosis.

2.3 *Reporting Proforma*

The participants were asked to report their findings on a standardized reporting form that was modified from the Royal College of Pathologist Guidelines for reporting non-operative diagnostic breast specimens[15] and UK breast pathology interpretive EQA scheme core needle biopsy proforma. This reporting form was divided into five sections to include the following domains:

Overall diagnosis:

1 B1 normal
2 B2 benign
3 B3 lesion of uncertain malignant potential—including epithelial proliferation with or without atypia
4 B4 suspicious
5 B5a malignant *in situ*—including nuclear grade and microinvasion
6 B5b malignant invasive—including type and grade

To minimize interruption in continuous eye tracking, the pathologists were asked to verbally report their findings to a research assistant who then recorded these on the reporting proforma.

2.4 *Workstation*

A dedicated workstation was set up in each pathologist's normal reading environment with controlled ambient light, in a Covid safe manner. The slides were viewed on a regular computer workstation with a 22-in single screen display with 1680×1050 pixels and an aspect ratio of 16:10. The scanned digital slides provided by the NIHR Digital Pathology study were viewed on this computer using a histopathology slide viewer, the Phillips Image Management System (IMS).[14] This system allows the display of each image at a standard resolution and allows panning and zooming of up to 100×. The pathologists were also provided with a standard mouse and keyboard for navigation, panning, zooming, and taking measurements.

Alongside the computer used to view images, there was a separate computer to monitor the eye-tracking data (Fig. 1).

2.5 *Eye Tracking Device*

A nonintrusive eye tracking device, SmartEyePro (Smart Eye AB), was used in this study. Three small eye-tracking cameras monitored participants' visual search behavior at a sampling rate of 60 Hz. A scene camera was also placed on the participant workstation to record the scene, to help identify any instances where data were lost (Fig. 1). The eye-tracking cameras were adjusted to suit each participant's head position and calibrated to ensure accurate eye and gaze tracking. Coupled with the eyesDX software application suite, participants' eye-tracking data, workstation screen capture, and the scene camera recording were automatically recorded and compiled in real-time.

2.6 *Experimental Design*

Before commencing each data collection session, the pathologists were provided with an information sheet explaining the study. After reading, written, informed consent was obtained from each participant before starting the experiment. Participants were then provided with an example set of eight cases to familiarize themselves with the viewing platform, Phillips IMS. The test set of digitized slide images was displayed on the monitor in the same order.

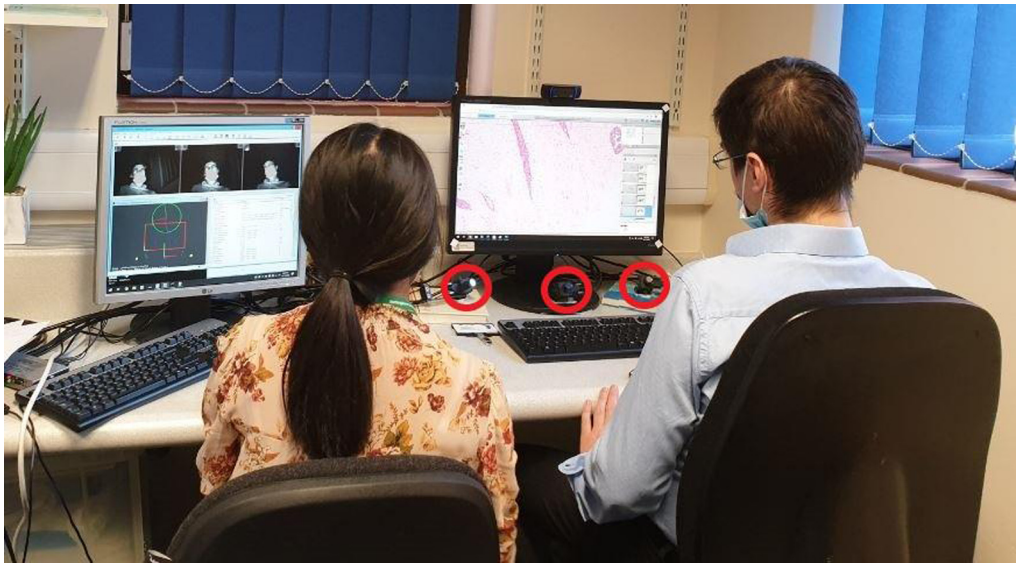

Fig. 1 An example of an experimental setup showing a participant and a research assistant. Two separate computers were used with three small eye-tracking cameras placed underneath participants' monitors, highlighted here in red circles. The monitor to the left was used for eye tracking calibration and monitoring but was not visible to the participant during the experiment.

The recordings were done in several parts depending on the time taken by the participants. We paused the recordings after approximately every 40 min to offload the high volume of data collected on the external drive to make space for more data. This process normally took 5 min. To allow for natural behavior, participants were allowed breaks as required.

2.7 *Data Processing*

We analyzed the video recordings using automated software developed by author PP to extract the data on magnification. This computer program enabled us to automate data extraction for the analysis of magnification values as shown in Fig. 2.

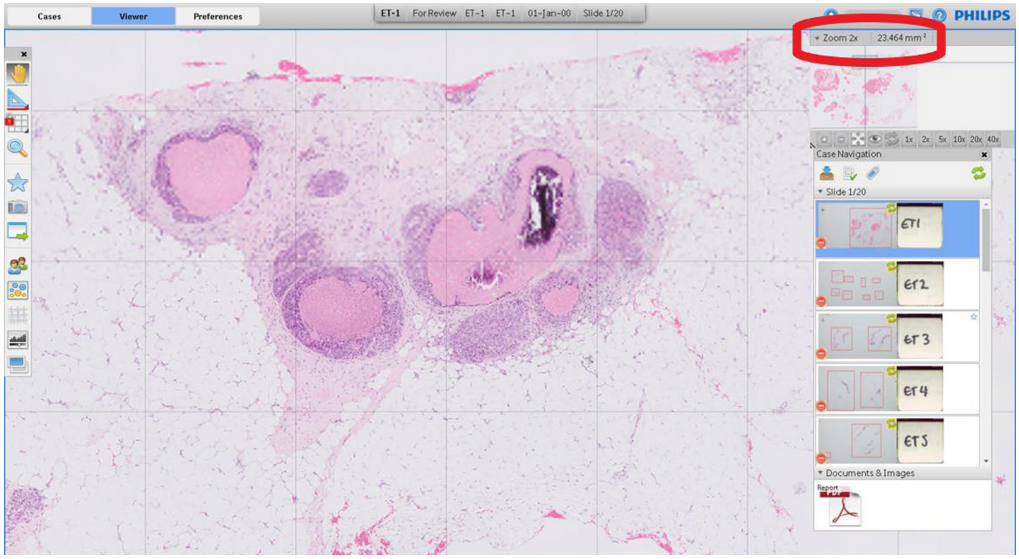

Fig. 2 An example of screen capture for a slide. The computer software extracts the zoom value automatically as it appears at the upper right-hand corner of the screen, here highlighted in red.

Information on case durations, fixation, magnification, and diagnostic accuracy using consensus diagnosis was extracted. In this study, the case durations were counted starting from the first initial full-screen appearance of the slide image until the disappearance of the slide image upon reading completion. Fixation was defined as a cluster of gaze points that were very close in time and space. Magnification was the use of the "zoom in" and "zoom-out" functions within the image slide viewer application. Diagnostic accuracy referred to the concordance of the diagnosis by a participant to the ground truth diagnosis.

For this study, "zooming" behavior refers to the action of zooming in and zooming out of magnification values, which was measured by the number of changes of magnification in a minute. "Panning" was defined as the total proportion of time spent on any single magnification for longer than 2 s.

2.8 *Statistical Analysis*

Average case durations, fixation, magnification, and diagnostic accuracy were assessed for each participant. Repeated measures analysis of variance (ANOVAs) was used to test for statistical significance, with posthoc pairwise t-tests with correction for false discovery rate using Benjamini–Hochberg method.

We investigated the relationship between experience and case durations, fixation, and magnification using mixed-effects linear regressions, with inverse transformations, wherever appropriate. Case ID was taken as the random-effects variable to account for within-slide correlations. The relationship between experience and diagnostic accuracy was investigated using mixed-effects logistic regression again taking case ID as the random-effects variable.

The threshold for statistical significance was set at $\alpha = 0.05$. Results are presented as mean $\pm$95% confidence intervals.

3 Results

3.1 *Case Duration*

A significant difference was identified between participants and case durations ($F = 10.77$, $p < 0.001$; Fig. 3). Participant 1, who had the least experience in pathology took on average 169.75 s (95% CI: 138.82 to 200.68 s), whereas participant 5 who had the most experience took on average 101.22 s (95% CI: 80.01 to 122.42 s). Post-hoc pairwise t-tests showed the

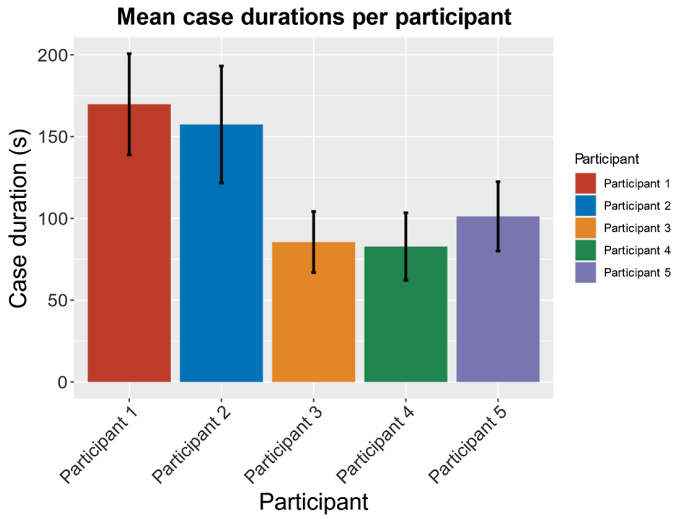

Fig. 3 Comparison of mean case durations in seconds per participant. The black bars denote the 95% confidence intervals of the means. Participants have been ordered in increasing lengths of experience.

Table 1 Pairwise *t*-test with Holm's adjustment for multiple comparisons of reading durations. Bolded *p*-values are significant.

	Participant 1	Participant 2	Participant 3	Participant 4
Participant 2	1.00000	—	—	—
Participant 3	**6.7e-05**	**0.00074**	—	—
Participant 4	**4.0e-05**	**0.00048**	1.00000	—
Participant 5	**0.00125**	**0.01047**	1.00000	1.00000

Fig. 4 A graph of case duration against years of experience. The line denotes the regression line. The shaded area denotes the 95% confidence interval of the regression line.

less experienced participants 1 and 2, with an average of 2 years of experience, exhibiting significantly longer reading times compared to the more experienced participants 3, 4, and 5 (mean years of experience: 25.67 years) (Table 1).

There was a clear and significant trend toward quicker reading times with increasing experience, with this relationship being inversely proportional ($p < 0.001$; Fig. 4). The changes were greatest for the first 10 years, which then levels off thereafter (Fig. 4).

3.2 *Fixations*

Figure 5 shows the average number of fixations per participant, with the least experienced participant (participant 1) having the greatest number of fixations (mean: 65.5, 95% CI: 56.0 to 77.0), and the most experienced participant (participant 5) having the least (mean: 33.1, 95% CI: 25.1 to 41.1).

The increasing experience was significantly associated with the reduced number of fixations per slide, in an inversely proportional manner ($p < 0.001$; Fig. 6).

3.3 *Magnification Use*

All pathologists exhibited a preference for 5× magnification for the majority of the examination session (Fig. 7). Furthermore, the more experienced pathologists utilized the lower magnifications more than the less experienced pathologists, and conversely, the less experienced pathologists utilized the higher magnifications more than experienced pathologists (Fig. 7).

Greater experience was significantly associated with greater relative use of the lower magnifications: 0.1× (effect size: 0.212% per year, 95% CI: 0.011 to 0.412, $p = 0.04$) and

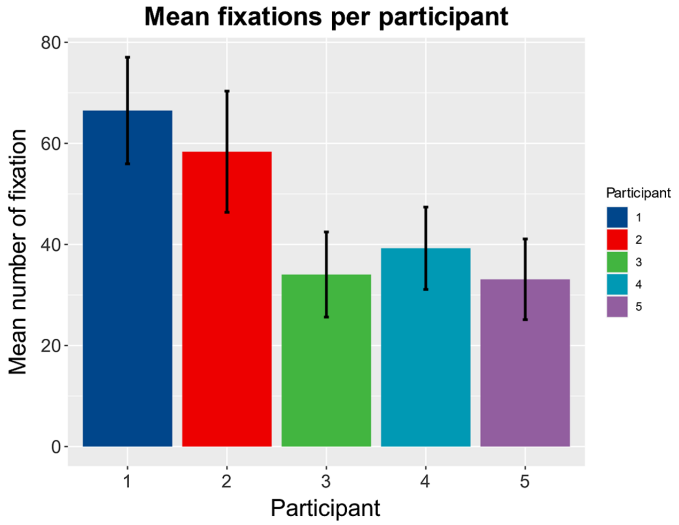

Fig. 5 Comparison of the mean number of fixations per participant. The black bars denote the 95% confidence intervals of the means.

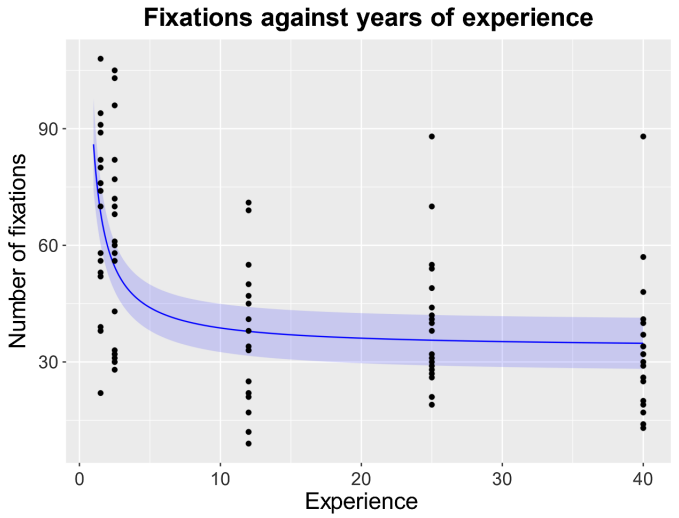

Fig. 6 A graph of fixations against years of experience. The line denotes the regression line. The band denotes the 95% confidence interval.

0.5× (effect size: 0.277% per year, 95% CI: 0.076 to 0.477, $p = 0.008$). In contrast, greater experience was significantly associated with lesser usage of higher magnifications: 5× (effect size: −0.342% per year, 95% CI: −0.542 to −0.141, $p < 0.001$) and 10× (effect size: −0.319, 95% CI: −0.520 to −0.118, $p = 0.002$).

Additionally, the experience was associated with a near significant decrease in the relative time spent panning in each case (−0.20% per year of experience, 95% CI: −0.42 to 0.02, $p = 0.070$; Fig. 8). There was, however, a significant association between experience and increased zooming behavior, as indicated by the number of magnification changes per minute (0.25/min, 95% CI: 0.15 to 0.35, $p < 0.001$; Fig. 9).

3.4 *Diagnostic accuracy*

Figure 10 shows the diagnostic accuracies of each of our participants by case. There was significant correlation between greater experience and overall diagnostic accuracy of each participant (log-odds: 0.050 per year, 95% CI: 0.007 to 0.100, $p = 0.033$) (Fig. 11).

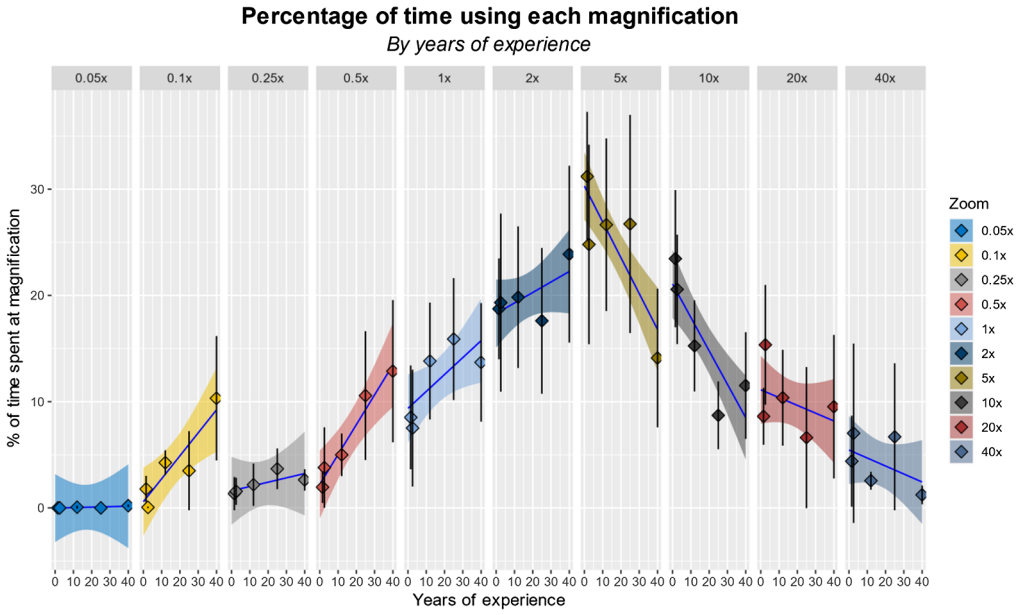

Fig. 7 Graph showing the percentage of time spent at each magnification against years of experience. The points denote the mean, the error bars denote a 95% confidence interval. The blue line shows the regression line. The shadowing represents the standard error of the regression line.

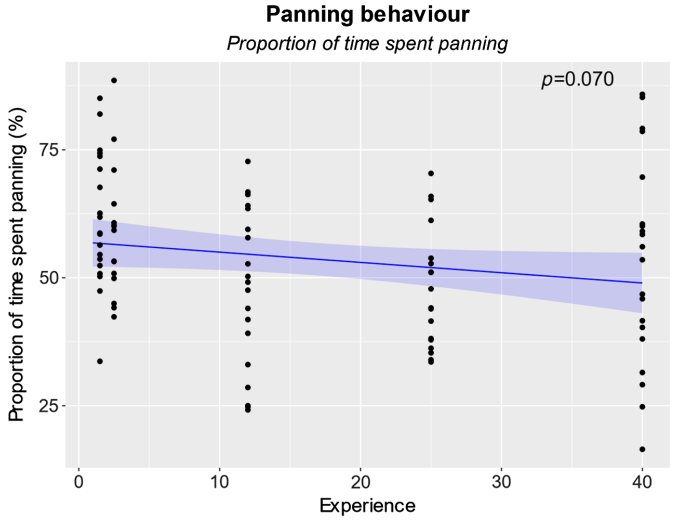

Fig. 8 Relative time spent panning by years of experience. The line denotes the regression line, and the shaded band denotes the 95% confidence interval of the regression line.

4 Discussion

The objectives of this study were: (1) to assess the visual search behaviors of pathologists using a digital pathology platform and (2) to investigate whether there were any differences in visual search behaviors between pathologists of varying experiences.

We found that greater experience was associated with a significant increase in "zooming" behaviors (Fig. 9) and a decrease in "panning" (Fig. 8). In addition, there was a significant trend toward lower magnifications for a greater proportion of the examination with increasing experience (Fig. 7). Furthermore, we found that not only do the more experienced pathologists require less time to reach a diagnosis (Fig. 4), but also fewer visual fixations to do so (Fig. 6), in agreement with previous findings.[7,16] This could be due to either more efficient visual search patterns, better pattern recognition, and greater visual processing capabilities or any

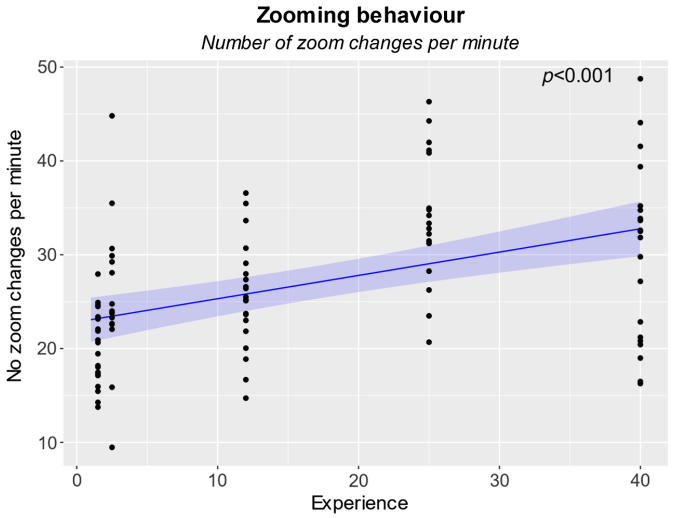

Fig. 9 Number of zoom changes per minute by years of experience. The line denotes the regression line, and the shaded band denotes the 95% confidence interval of the regression line.

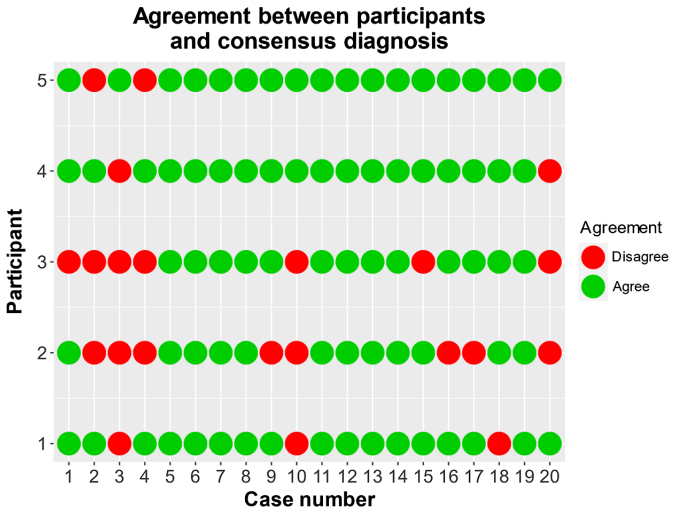

Fig. 10 Agreement between participants and consensus diagnosis. Green dots represent agreement with consensus diagnosis, and red dots represent disagreement.

combination of these factors and the relevant factors at play may differ between pathologists. The regression lines of both metrics exhibited a tendency to plateau at around 10 years of experience.

Finally, the internal validity of our study was shown by confirming a highly significant association between experience and diagnostic accuracy (Fig. 11), in keeping with our previous study[17] and existing literature.[18]

4.1 *Magnification Use*

We classified the magnification use of our participants into "zooming" and "panning" actions. A study by Mercan et al.[11] found a significant association between "panning" (called "scanning" by the authors) and slower interpretation times compared to "zooming" (called "drilling" by the authors) in pathologists. A similar effect was described in radiology by Drew et al.,[19] who found that drilling strategies were associated with better performance on a variety of metrics. Drew et al.[19] postulated in their studies of radiologists that the better performance of drillers may be an effect of more experienced radiologists learning to use drilling strategies. Our study provides evidence in support of this hypothesis. The highly significant association between

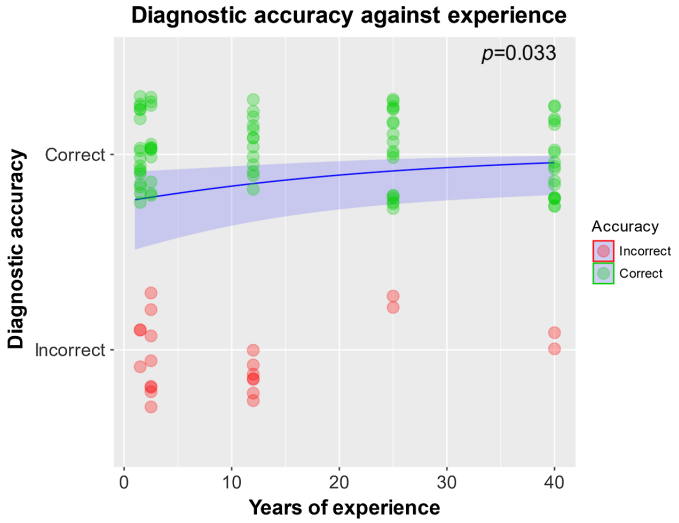

Fig. 11 Graph showing the relationship between diagnostic accuracy and years of experience. Green dots represent correct diagnosis, and red dots represent incorrect diagnosis. The line denotes the logistic regression line. The shaded band denotes the 95% confidence interval. The points are randomly scattered around the *y* axis for the clarity of individual points.

experience and "zooming" behaviors, alongside our confirmation that greater experience results in better diagnostic accuracy and reading speed, suggests this explanation as to the most likely mechanism of the observed effect.

Surprisingly, a recent digital breast pathology eye-tracking investigation from Drew et al. (2021), with large sample size, demonstrated that actually more "panning"/"scanning," but not "zooming"/"drilling" behavior was associated with diagnostic accuracy, which would seem to contradict our findings.[13] However, their sample consisted of an uneven balance of attendings and residents, and hence experience. They noted that no significant correlation between time on task and diagnostic accuracy was identified in their sample, which also surprised the authors. They mentioned that this could have been linked to the uneven experience in their sample and they explain that they would be interested to analyze if/how experience correlates with time on task once they've increased their sample of attendings in the future. It would be interesting to reassess the observed "panning" and "zooming" behavior again with this new sample in a similar fashion proposed for time on task.[13]

An additional finding of our study was that 5× zoom was the most frequently used magnification value for the interpretation of breast pathology slides. The time spent on other magnifications is approximately normally distributed around that value (Fig. 7). Similar to Treanor et al.[20] we found that more experienced pathologists had significant tendencies toward lower magnifications, whereas less experienced pathologists exhibited significant tendencies toward higher magnification values. This is consistent with Mercan et al.[11] and Brunyé et al.,[12] who observed an association between higher magnifications and errors arising from overinterpretations. Our findings lend further support to the current and widely taught practice of utilizing low power assessment of the slide to decide which areas of the slide are most important and merit high power assessment.

4.2 *Visual Processing Capabilities*

Our study allows an indirect assessment of visual processing cognitive capabilities and is suggestive of improved visual processing with greater experience. The crudest of these are the findings of significant improvements in reading speed with greater experience (Fig. 4), with greater accuracy (Fig. 11).

Moreover, we found that it took significantly fewer visual fixations to reach a diagnosis for experienced pathologists compared to inexperienced pathologists. In addition, greater zooming frequency among more experienced pathologists was indicative of greater visual processing speeds and better pattern recognition.

It may be the case that experience develops the cognitive capabilities that are prerequisites for zooming behaviors. This could be an explanation for the tendency to dwell longer within a higher magnification value for less experienced pathologists who are yet to possess these cognitive capabilities.

4.3 *Future Directions*

One limitation of our study is the small sample size. Although we did not find that it affected the power to detect statistically significant differences, it may limit the external validity of our study, perhaps explaining the discordance of our results about "zooming" and "panning" behavior as compared to the study from Drew et al., as discussed previously.[13] This also meant that there was relatively poor coverage of experience among the group of inexperienced pathologists as there were too few junior trainees. Although our analysis suggested a plateauing of certain outcome measures at around 10 years, this figure cannot be regarded with any certainty until further work is done among this group of early-career pathologists. Therefore, future work may wish to elucidate the point at which this plateau in performance metrics is reached by recruiting these early-career pathologists.

Our study has also elucidated experience as a confounding factor for any study wishing to assess for a causative relationship between magnification use or visual search behaviors, and performance. Future studies, therefore, may wish to control for this confounding factor either during recruitment or during statistical analysis.

5 Conclusions

Experienced pathologists made greater use of lower magnification compared to inexperienced trainees. Zooming behavior (changing zoom values) was seen to be more prevalent among experienced pathologists, whereas panning behavior (dwelling on any single magnification) was more prevalent among inexperienced pathologists. We found evidence that greater experience develops visual processing capabilities, which may be a prerequisite for zooming behaviors. Further research into these and other characteristics of expertise development in DP image interpretation, as well as increasing sample size and pooling participants from different centers in future studies, could demonstrate the use of these behaviors as markers of expertise in training programs. As trainee pathologists progress through their education, eye-tracked test sets of DP images could be scheduled. Breaking down recorded interpretation behaviors alongside diagnostic performance and comparing these breakdowns throughout their training could help evidence their progression and expertise development.

Disclosures

The authors declare that there is no conflict of interest.

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Code, Data, and Materials Statement

Code and data have not been uploaded, but can be made available from the corresponding author by request.

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