

Slide navigation patterns among pathologists with long experience of digital review

Jesper Molin,^{1,2,3} Morten Fjeld,¹ Claudia Mello-Thoms⁴ & Claes Lundström^{2,3}

¹t2i Interaction Laboratory, Department of Applied Information Technology, Chalmers University of Technology, Gothenburg, Sweden, ²Centre for Image Science and Visualization, Linköping University, Linköping, Sweden, ³Sectra AB, Linköping, Sweden, and ⁴Medical Radiation Sciences, University of Sydney, Sydney, NSW, Australia

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Aims: In order to develop efficient digital pathology workstations, we studied the navigation patterns of pathologists diagnosing whole-slide images. To gain a better understanding of these patterns, we built a conceptual model based on observations. We also determined whether or not new navigation patterns have emerged among pathologists with extensive digital experience.

Methods and results: Five pathologists were asked to diagnose a set of four cases while thinking out loud. The navigation within the digital slides was recorded and divided into re-occurring navigation actions. The pathologists reused the same type of actions, but their occurrence differed. The most common action was a

slow panning that followed an edge structure or covered an area systematically, which accounted for 30.2% of all actions and had a median duration of 7.2 s. Of all the actions, 49% were carried out within the navigation overview and 38% of the actions could not have been performed with a conventional microscope.

Conclusions: The new navigation possibilities in the digital workstation were used to a large extent. The division of actions into different concepts can be used to find and prioritize between existing user interface designs as well as to understand the different navigation styles used by different pathologists.

Keywords: classification of movement, digital pathology, multiscale navigation, useability

Introduction

The use of digital pathology as a tool within primary review has become more widespread in recent years;^{1,2} however, large-scale use for primary review is still uncommon.³ In a recent study of experiences from extensive primary review using whole-slide imaging,⁴ a clear improvement potential for the digital workstation was identified. Suggested improvements were lag-free navigation, further possibilities for navigation control and more suitable input

devices. Digital workstations have still not enhanced convenience in case reporting or made diagnostic reviews faster. These findings were echoed in a recent study in the United States, where 78% of the responding pathologists considered digital review to be too slow for routine work.⁵

In order to understand the underlying causes of the limited success of the digital tools, the diagnostic process needs to be studied in detail. Crowley *et al.*⁶ studied pathologists' verbal reasoning and described the diagnostic process in terms of detecting findings and incorporating them with knowledge to form hypotheses. In another study, pathologists' eye movements were divided into scanning and selective types,⁷ which were attributed to a difference in expertise.⁸ Other evidence suggests, however, that trainees

Address for correspondence: J Molin, t2i Interaction Laboratory, Department of Applied Information Technology, Chalmers University of Technology, Göteborg 41296, Sweden.
e-mail: mjesper@chalmers.se

look at and identify the same findings as experts, but fail to give a correct diagnosis.^{6,9,10} In a series of studies,^{10–14} it was found that digital review can be as fast as conventional microscopy.^{13,14} To achieve those results they used a large high-resolution display, lag-free image rendering and a decreased interaction cost to switch between slides.

One area that has been given less attention is the navigation of digital slides. Navigation tracks have been recorded,^{9,10} but used only as a proxy for measuring visual attention. However, navigational movements might be important to facilitate the mental reasoning involved in diagnostic review. It has been shown that physical actions can make mental computation easier, faster or more reliable.¹⁵ Already, pathologists make use of multiple actions that relieve working memory, such as turning reviewed slides upside-down¹² or using a lawnmower search pattern,¹⁶ both strategies to keep track of areas already reviewed.

Within radiology, two alternative navigation styles to search for nodules in lung computerized tomography (CT) image stacks were identified.¹⁷ The first style consisted of searching each image slice completely. The second style was to fix the gaze on one quadrant and scroll quickly through the CT stack multiple times, resulting in increased detection rates. The second style is possible only in a digital environment. Thus, the digitization of radiology led to a new navigation behaviour observed in radiologists. Will the same happen when pathology image review becomes digital?

As we see it, to improve digital pathology workstations there is a need for better knowledge of how pathologists navigate slides. Therefore, with this study we aim to (i) increase the understanding of navigation by building a conceptual model based on observation and (ii)

investigate whether new navigation patterns have emerged among early adopters of digital pathology.

Material and methods

This study was approved by the local institutional review board (2013/195-31).

To observe and model pathologists' navigation, two methods of data collection were combined. First, we recorded navigation actions when pathologists were diagnosing cases of histological specimens. Simultaneously, think-aloud statements of the diagnostic reasoning were recorded and correlated with the navigation strategy used.

Participating pathologists were recruited by sending an e-mail request to all pathologists at the Kalmar County Hospital and Linköping University Hospital, where whole-slide imaging has been used for primary diagnostics since 2008 and 2010, respectively.⁴ Each individual pathologist's experience with digital review was verified using pre-interviews in order to ensure that they were able to navigate whole-slide images comfortably; thereby, one of the recruited pathologists was excluded. A sample of five pathologists representing interested early adopters of digital pathology remained, all with specialist training and normal or corrected to normal sight.

Four different cases were selected from the digital image database of the Pathology Department of Linköping University Hospital. The cases varied in type, staining, number of slides and the number of sections per slide; however, subspeciality training was not required to review them. The case information was anonymized, but otherwise not changed. The cases are listed in Table 1.

Table 1. List of the cases used in the study

Number	Diagnosis	Stainings	Number of slides	Average number of sections per slide
Case 1	Perforated flegmoneous appendicitis	All H&E	3	1.66
Case 2	Benign melanocyte naevus	All H&E	2	2
Case 3	Invasive ductal breast carcinoma	6 H&E, 1 ER, 1 HER2, 1 PGR, 1 Ki-67, 1 PHH3 + 3 slides from prior cases of the same patient	14	1.07
Case 4	Malign melanocyte skin tumour	2 H&E, 1 HER2, HMB, 1 Ki-67, 1 Melan, 1 S100	6	2.66

H&E, Haematoxylin and eosin; ER, oestrogen receptor; HER2, human epidermal growth factor receptor 2; PGR, progesterone receptor; Ki-67, antigen Ki-67; PHH3, phospho-histone H3; HMB, human melanoma black; Melan, melanoma A.

The cases were diagnosed using a prototype workstation with lag-free display that had been developed within a Swedish digital pathology project. To review the digital slides, a 27", UltraSharp U2713HM (Dell Inc., Round Rock, TX, USA), 4-megapixel display was used, and to display patient information, a smaller 15" laptop display was used. The user interface of the large display provided a main view, a navigation overview and clickable thumbnails of slides corresponding to the open case. To control the workstation, a computer mouse with two buttons and a scroll wheel was used. This setup provided two new ways to navigate within the slides compared to a conventional microscope. First, it was possible to use the navigation overview to jump directly to a location within the slide outside what was visible within the main view without first having to zoom out. Secondly, it was possible to increase the magnification around the mouse pointer instead of the centre of the display, as in the microscope. Besides these new possibilities, it was also practicable to navigate as with the conventional microscope, in terms of how the hand movement was mapped to the displayed digital image. The navigational possibilities of the conventional microscope could therefore be seen as an approximate subset of the navigational possibilities of the digital workstation. Figure 1 shows the experimental setup.

The pathologists received training in using the workstation and were instructed to think aloud in compliance with recommendations and previous related research efforts.^{6,18,19}

The think-aloud statements were recorded and transcribed. The navigation was recorded using the prototype software. The display of the workstation and the mouse pointer position were recorded using

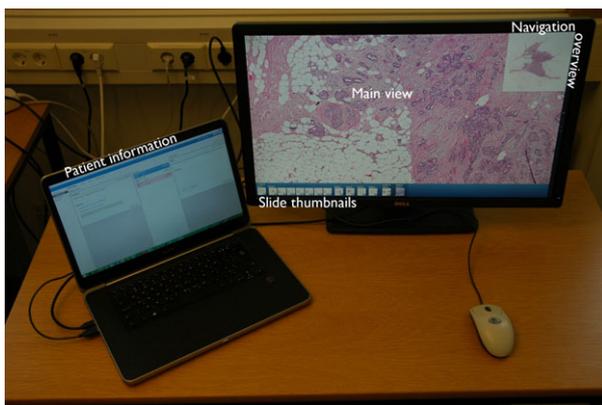


Figure 1. The experimental setup consisting of a laptop to show patient information and a 27", 4-megapixel display to display images.

CamStudio (version 2.7; <http://camstudio.org>). The recorded data were synchronized and visualized using an interactive version of Space-scale diagrams²⁰ in order to facilitate the derivation of navigation patterns.

Within the interactive visualization it was possible to analyse the navigation patterns in the context of the histology image. Distinct pan and zoom combinations that were reused frequently within and between participants were identified, referred to as 'navlets'. The identification process resulted in specific coding rules. Dwell time between coded navlets and user errors that terminated the navigation, such as accidentally closing the software, were excluded from the analysis, whereas accidental pans and zooms within a navlet were retained.

The coding rules were applied on the navigation tracking recordings within the interactive visualization by two independent coders (J.M., C.L.). The coders lacked training in pathology, but had a basic understanding of the content in the histology images as well as a good understanding of the possibilities for navigation within the prototype software. Discordant codes were resolved at a consensus conference.

The frequency and median duration for each navlet category were derived, as well as the percentage of navlets performed within the navigation overview.

Finally, the cognitive motivation for each navlet was analysed by stepping through the corresponding recordings and the transcribed think-aloud statements.

Results

The analysis yielded six different types of navlets: three types of panning and three types of zooming. In total, 918 navlets were identified, with an inter-rater agreement of 80.0%. Discordant codes were resolved before statistical measures were derived. Definitions, frequencies and durations are given in Table 2. Depictions as Space-scale diagrams²⁰ are provided in Figure 2. The fractions of the total time spent per navlet type by different pathologists and on different cases are given in Figure 3.

Forty-nine per cent of the navlets were performed within the navigation overview, excluding those of pathologist B due to a logging error. The subset of actions not available in a conventional microscope consisted of zooming-in and dip-zooming in the main view, and directed panning in the navigation overview. This subset accounted for 38% of all actions. Per-pathologist percentages are given in Table 3.

Table 2. Definitions of the different navlets; distinct pan and zoom combinations that were frequently reused within and between participants. Occurrence is reported as percentages and the duration as median values and interquartile ranges (IQR)

Name	Definition	Percentage of occurrence	Median duration (IQR)
Directed panning	A quick pan from one point to another	18.7	1.2 s (0.3 s, 2.2 s)
Cover panning	A slow type of panning following an edge structure or systematically covering an area	30.2	7.4 s (4.5 s, 12.9 s)
Sporadic panning	A slow type of panning without specific direction or systematic coverage	11.1	5.2 s (3.3 s, 9.9 s)
Zooming-in	An increase in magnification, directed or undirected on a specific image feature	20.7	1.9 s (1.2 s, 3.5 s)
Zooming-out	A decrease in magnification, always undirected	10.6	1.8 s (1.0 s, 2.8 s)
Dip-zooming	A specific in-zooming on a specific image feature followed by zooming-out	8.7	4.3 s (3.0 s, 6.3 s)

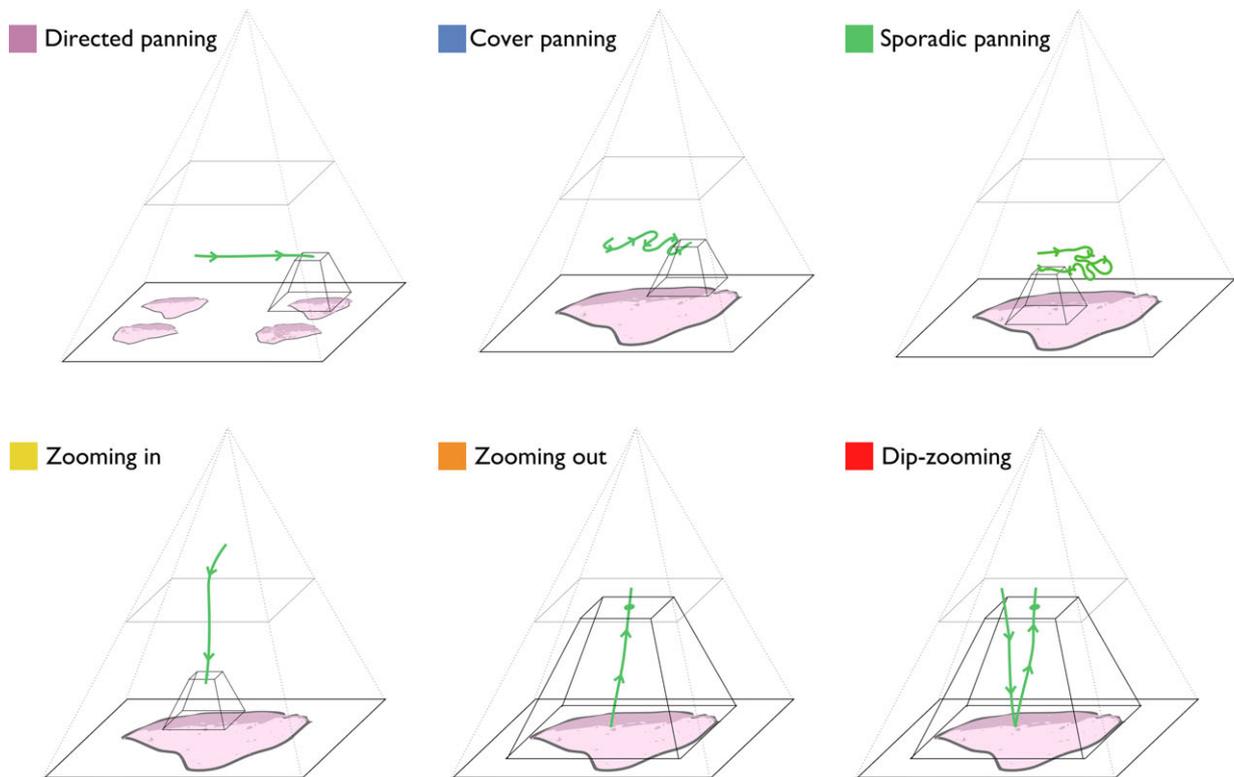


Figure 2. Different types of navlets, distinct pan and zoom combinations that were reused frequently within and between participants, which the pathologists in the study used when reviewing the digital slides.

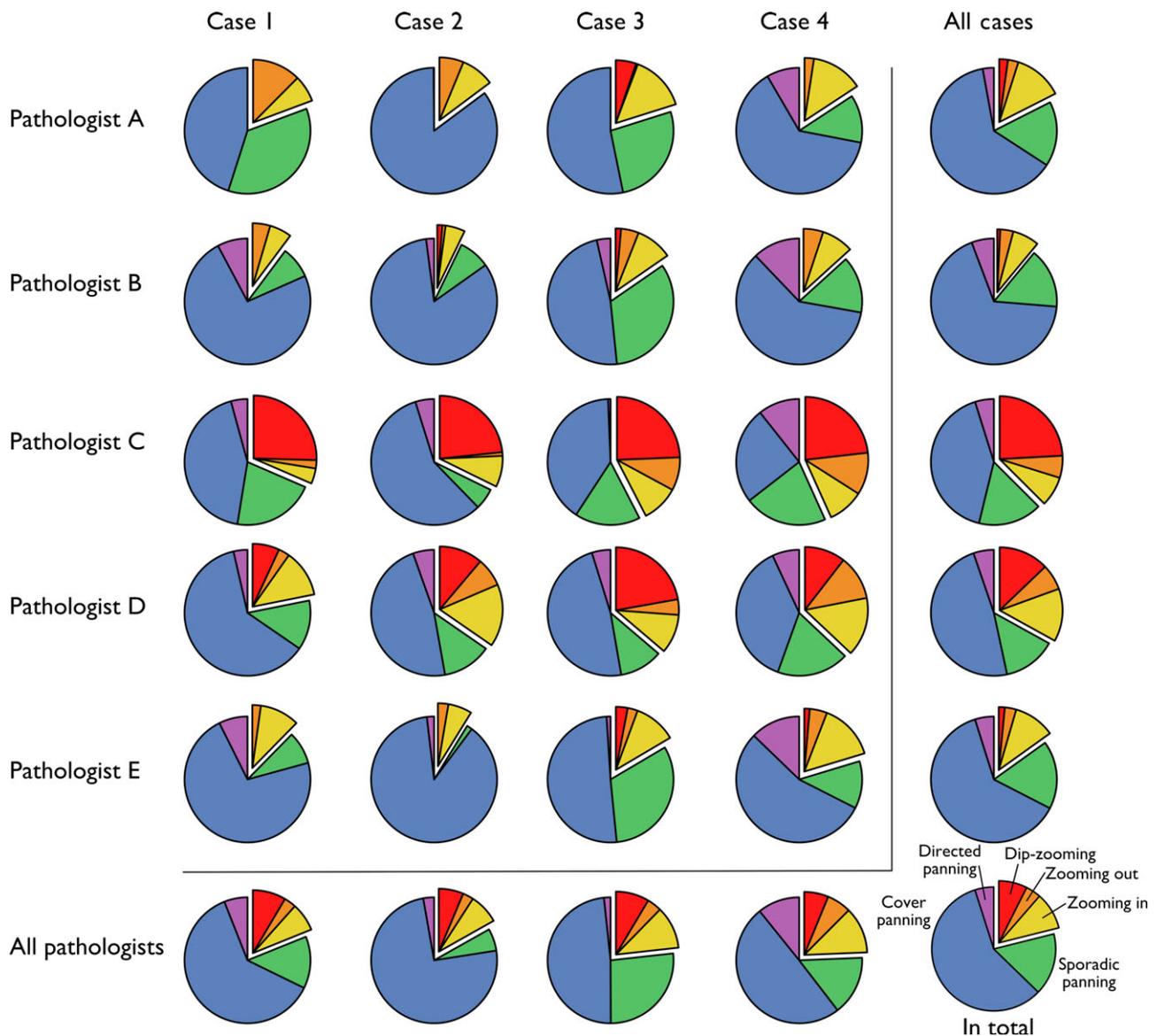


Figure 3. The time spent performing different navlets ordered per pathologist and case. Under 'All cases' the different columns to the left have been summed horizontally and the 'All pathologists' row correspond to vertical sums. The down/right chart corresponds to the time spent overall. The colours in the pie charts correspond to the navigation segments that were defined in Figure 1. The pie pieces that correspond to different kinds of zooming have been lifted out in each chart to highlight the difference in balance between panning and zooming.

A summary of the analysis of what the different navlets were used for is given below.

DIRECTED PANNING

This quick panning was used mainly as transport between sections on the same slide. Sometimes it was performed in cycles: searching for one detail at a time in all sections, and then starting again at the first section to search for another detail in all sections. In large sections this kind of pan was also used to move quickly

between points of interest, as well as to revisit quickly a location already reviewed for comparison purposes.

COVER PANNING

This navlet was used mainly by the pathologists to search for a predetermined finding. It was common to redo this navlet on the same edge or area in order to search for another finding. Careful cover panning made it possible to conclude on the absence of a finding. The navlet was also used at the beginning of

Table 3. The percentage of the different actions that were carried out within the navigation overview

	Directed panning (%)	Coverage panning (%)	Sporadic panning (%)	Zooming-in (%)	Zooming-out (%)	Dip-zooming (%)
Pathologist A	25	0	0	0	0	0
Pathologist C	91	49	7	26	0	4
Pathologist D	96	84	61	37	50	31
Pathologist E	100	87	67	35	52	10
Total	91	62	37	28	28	9

reviewing a slide for a non-specific search at low magnification, whereas non-specific searches were not carried out at high magnifications. The navlet was also used as a part of formal protocols, such as proliferation grading. When covering larger areas without an edge to guide the navigation, a lawnmower pattern was used to keep track of visited areas. One of the pathologists used the lawnmower pattern repeatedly instead of following edge structures.

SPORADIC PANNING

This navlet was used mainly to conclude on the presence of a finding or to sample quickly an area of interest. The navlet was used for both specific and non-specific exploration in the same way as cover panning; the largest functional difference between them was that sporadic panning did not allow a conclusive decision on the absence of a finding.

ZOOMING-IN

The zooming-in navlet was used mainly to set a start location for panning. By pointing at an area of interest at low magnification and zooming using the scroll wheel, this action set a useful magnification level for the task at hand as well as making the pathologist aware of the current location. When the navigation overview was used for this action, the pathologist centred the viewport above the point of interest and then scrolled, as some would do with a conventional microscope. The zoom level was set mainly by zooming to a comfortable level of detail for the task at hand; sometimes, however, the pathologists knew the numerical value of the desired magnification beforehand.

ZOOMING-OUT

The zooming-out was not directed. It was used to gain an overview of the slide and to switch to a

different subtask within a slide. The navigation of almost every slide ended with a zooming-out before switching slides.

DIP-ZOOMING

This navlet was used mainly for two purposes. The first was to view a finding quickly, visible initially at low magnification, at higher magnification. This action was sometimes performed while the pathologist made a statement of the finding's location. The other purpose was to sample the morphology quickly at high magnification of what, at low magnification, appeared to be a coherent area. Dip-zooming was carried out typically by pointing at a location of interest with the mouse and scrolling-in. One user tried to double-click on points to perform this action, which was unsupported in the prototype, but transitioned during the trial to use the scroll wheel instead.

Discussion

Overall, navigation techniques exclusive to the digital workstation have been adopted extensively. The navigation overview was used for many of the panning tasks, which is in line with studies from other similar non-medical domains showing that a navigation overview is preferred.^{21,22} This study shows the same pattern as that from Drew *et al.*,¹⁷ who also identified a style of navigation that was incompatible with pre-digital review within radiology. Comparative studies between conventional and digital microscopy should therefore ensure that participants have enough digital experience or training in order to avoid results that favour conventional microscopy. Designers of digital workstations should also make use of existing usability research on the review of large images with a computer rather than trying to re-implement the microscope. The division of the navigation into navlets can aid the identification of existing designs and

to prioritize between them; for example, improving cover panning can be aided by conclusions from a study of steering tasks,²³ and directed panning can fall under Fitts' law²⁴ and its multiscale formulation.²⁵

The pathologists each had their own style, which was fairly consistent between cases. While the number of participants was too low in this study to make generalizations about different styles, it can be seen that pathologists C and D were dip-zooming much more than the others. This behaviour should not be confused with earlier findings that more time was spent at high magnification when residents gave an incorrect diagnosis,⁹ or that trainees spent more time there,¹⁰ as C and D were experienced pathologists with extensive digital experience. It is more likely that the actual cause was the increased convenience of dip-zooming with the digital workstation.

Zooming-in, zooming-out and directed panning have in common that the faster they can be performed, the better they work, as the pathologists do not collect image information for the review while these are being carried out. Directed panning could probably be performed faster if a function that jumps between sections was introduced. Because directed panning was used to search for the same detail in multiple sections, that function should be cyclic and preserve magnification between jumps. In contrast, cover panning, sporadic panning and dip-zooming are limited by the pathologist's visual perception and information processing capacity.

We can hypothesize that small variations of the navlet distribution will probably occur with different case types, display sizes and input devices. The amount of directed panning would increase with the number of sections or regions of interests in a slide. Large high-resolution screens have been shown to reduce the time needed for initial review in case viewing,²⁶ even though foveal search takes longer to perform with the larger display.²⁷ A reason for this is that the resolution positively affects the number of search tasks carried out using our peripheral vision while reducing the need for relatively slower cover panning. We expect that screen resolution also potentially could increase the amount of dip-zooming. That is, when feature detection is performed at a relatively low magnification, subsequent dip-zooming is sufficient for quick verification. With regard to influence from input devices, a key factor is whether the device uses rate control (e.g. game pad) or position control (e.g. mouse). There is, for instance, reason to believe that cover panning would be more comfortable to perform with a rate-controlled device. Moreover, it

should be noted that a lag-free display is a necessary prerequisite to avoid disturbance of the navigation patterns. Apart from the above external factors, internal factors such as the individual's perceptual and attentional abilities are equally important as the navigation behaviour is formed.

We argue that future research and development to improve digital pathology workstations would benefit from making use of the conceptual model presented in this paper. We suggest focusing particularly on areas which are known to be cumbersome, such as certain case types or specific subtasks.

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Conflicts of interest

J.M. and C. L. are employed by Sectra AB.

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