Title

Visual distraction in cytopathology: should we be concerned?

Running headline

Visual distraction in cytopathology

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Abstract

Objective

Visual distraction in cytopathology has not been previously investigated as a source of diagnostic error, presumably because the viewing field of a conventional light microscope is considered large enough to minimise interference from peripheral visual stimuli. Virtual microscopy, which involves the examination of digitised images of pathology specimens on computer screens, is beginning to challenge the central role of light microscopy as a diagnostic tool in cytopathology. The relatively narrow visual angle offered by virtual microscopy makes it conceivable that users of these systems are more vulnerable to visual interference.

Using a variant of a visual distraction paradigm (the Eriksen flanker task), the aim of the study was to determine whether the accuracy and speed of interpreting cells on a central target screen is affected by images of cells and text displayed on neighbouring monitors under realistic reading room conditions.

Methods

Following a brief period of training, 31 cytology novices undertook four cell interpretation tests under different conditions of visual distraction. Error rates were measured under each condition.

Results

There was no effect of visual distraction on diagnostic accuracy.

Conclusions

To the extent that the results from cytology novices extend to experienced practitioners, visual distraction is an unlikely source of error in virtual microscopy. Efficient visual selection and spatial attention, coupled with the high perceptual load of target images and the peripheral location of distractors, provide plausible explanations for the observed results.

Key Words

Cytopathology, Visual Perception, Cognition, Distraction, Virtual Microscopy.

Introduction

Although light microscopy is the traditional technique for examining cell morphology, virtual microscopy is increasingly being used, whereby digital images of whole glass slide samples are viewed on a computer display [1,2,3] The virtual microscope is different to the light microscope in several respects. In addition to the obvious differences between a digital display screen and an optical field of view, the angle subtended by the viewing field of the virtual microscope display is relatively small. Simple trigonometric calculations indicate that the visual angle offered by a monitor with a screen width of 33cm and a working distance of 50cm is approximately 30^{o}, compared with 55^{o} provided by a light microscope equipped with standard FN22 oculars. As a result, irrelevant background objects may be visible during the examination of virtual microscopy images that are not evident when assessing specimens by light microscopy. It is therefore conceivable that background visual stimuli, such as images of cells and other objects on nearby computer screens, might interfere with the interpretation of virtual microscopy images and may lead to diagnostic error.

To the best of our knowledge, visual distraction as a source of diagnostic error has not been previously studied in cytopathology. Extrinsic factors influencing the diagnostic performance of cytologists have been a subject of interest and concern for many years. In 2003, the National Health Service Cancer Screening Programmes (NHSCSP) in the UK commissioned the Applied Vision Research Unit of the University of Derby to consider the ergonomic factors that might influence the performance of cytologists while they undertake routine microscopy tasks. The survey resulted in recommendations intended to minimise the adverse health effects associated with poor workplace ergonomics and to maximise cytologist productivity and diagnostic performance.[4] The NHSCSP guidelines mentioned workplace distractions as a potential source of error and lost productivity, but provided no evidence for this claim.

In cognitive science, the effect of irrelevant visual stimuli on the detection and interpretation of target objects is called the *flanker compatibility effect.*[5,6] Far from being ignored, irrelevant background stimuli (flankers) can inhibit the ability of an observer to recognise target stimuli. In the original flanker experiment, participants responded to target letters that appeared on a display screen with flanking "noise" letters. In their original study, Eriksen and Eriksen found that participants responded significantly faster and with greater accuracy when flankers were identical to targets (*compatible* trials) than when they were different (*incompatible* trials). The corrupting effect of flanking letters was found to decrease asymptotically as the spacing between letters increased, but all flanker conditions yielded significantly slower response times and more errors than the target-alone condition. From experiments such as these, it is clear that observers have great difficulty ignoring task-irrelevant visual stimuli when focussing on a central task, even when specifically instructed to do so. An important consideration for the present study was that Eriksen and Eriksen did not investigate the effect of target-flanker separations beyond 1^{o} of visual angle.

The flanker compatibility effect raises an obvious practical question in cytology. Depending on room layout and workstation design, there is the intriguing and worrying possibility that background visual stimuli might influence the ability of cytologists to selectively process the information contained in microscopy images while trying to ignore extraneous visual information. Put simply, visual distraction might lead to diagnostic error. Importantly, current ergonomic recommendations[4] make no provision for the visual distractions that might influence the diagnostic performance of cytologists during virtual microscopy tasks. Even without consideration of virtual microscopy, the wider viewing field enjoyed in light microscopy does not imply that it is impervious to visual distraction.

To begin to address these practical issues, it is important to design ecologically valid experiments while protecting their internal validity. For clinical relevance the present study employed images of cells as target and flanker stimuli, thus mimicking a virtual microscopy setup. Non-cell flanker stimuli that might be encountered in the cytology reading room were also of interest, such as text on nearby computer screens. By subjecting a group of cytology novices to cell interpretation tests under these realistic flanker conditions, we predicted that visual distraction would result in lower test accuracy compared with a no-distraction control condition.

Materials and methods

Participants

The experiment was approved by Cardiff Metropolitan University School of Health Sciences Ethics Committee. Thirty-one undergraduate students (12 males aged 18-43 and 19 females aged 18-28) were consented to take part. All participants reported normal or corrected-to-normal vision. A power calculation confirmed that the sample size was sufficient to detect a moderate effect with power 0.8, assuming a repeated measures design with one factor (visual distraction) and four levels (no flanker, text, normal cells and abnormal cells).[7]

Apparatus

The experiment was conducted using 17-inch liquid crystal colour monitors with a resolution of 1024 pixels x 768 pixels and running from *IBM* personal computers. Microsoft *PowerPoint* was used for presenting training images and flanker stimuli while *DMDX* software was used for presenting test images and recording participant responses.[8]

Stimuli

A total of 140 digital images of single epithelial cells were acquired from cervical cytology samples at x400 magnification, using a *Colourview II* digital camera (Soft Imaging System Ltd, Helperby, North Yorkshire, England) mounted on an *Olympus BX51* microscope. (Olympus, Tokyo, Japan). Ground truth diagnostic status for each image was established by expert consensus agreement between three trained cytologists, each with over 20 years' experience.

Forty of the 140 cell images were arranged into 20 normal/abnormal pairs for training purposes and incorporated into a Microsoft *PowerPoint* slideshow. An example of one such image pair is shown in figure 1.

Figure 1 here

The same 20 image pairs used for training were rotated through 180^o and then inverted to produce a post-training practice set.

Sixty of the 140 cell images were compiled into a test set and embedded into *DMDX* software. The test set consisted of 30 normal and 30 abnormal cells in random order. Three further 60-slide test sets were assembled, first by rotating, then by inverting and finally by flipping the images in the original test set. This manipulation served to minimise memory effects that may arise from repeatedly exposing participants to the same images, whilst ensuring the same level of interpretive difficulty for repeated tests. An example test image is shown in figure 2. None of the images used for training or practice were employed as test stimuli.

Figure 2 here

Finally, three sets of flanker stimuli were compiled, each consisting of 20 images. One flanker set consisted of normal cells only, another consisted of abnormal cells only and a third set contained passages of text from a local health and safety policy document and were considered to be irrelevant to the focal task. The font style and size was typical of that used for reading from computer screens (Arial style, size 12). A no-flanker condition consisting of a plain white screen was also produced. Each flanker image was displayed in *PowerPoint* full screen mode and slides were set to automatically advance at 3 second intervals. The slideshow was programmed to loop continuously to avoid interruptions during the experiment. None of the cell images designated as flankers were used for training, practice or testing purposes.

Cell interpretation training

All participants received initial cell interpretation training by examining 20 pairs of images on a computer screen. Each image pair comprised a normal cell and an abnormal cell. The cell images were given the labels “normal” or “abnormal” but explicit tuition in the form of diagnostic feature lists was not provided. The effectiveness of this training strategy was demonstrated in our previous studies.[9,10] Participants examined another 20 non-annotated image-pairs for practice.

Cell interpretation tests

Interpretation tests consisted of 30 normal and 30 abnormal cell images in random order. Participants were instructed to respond only to the central cell in each image. In addition to deciding “normal” or “abnormal” for each test image, participants provided a confidence rating on a 1-to-5 ordinal scale using a computer keyboard. The *DMDX* software automatically recorded the response to each test image.

Design

A counterbalanced within design was adopted (figure 3), with type of flanker type as the within group independent variable and error rate as the dependent variable.

Figure 3 here

Procedure

Following training and practice, participants undertook four consecutive image interpretation tests under different flanker conditions, with three minutes rest between tests. The flanker sequence was counterbalanced across participants. All tests were carried out in virtual microscopy format in an environment that mimicked a typical cytology reading room. The workstation layout and positioning of flanker stimuli are illustrated in figure 4.

Figure 4 here

Statistical analysis

Error rates were subjected to repeated-measures ANOVA. Statistical analysis was conducted using *SPSS* software (IBM Corp. 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.) and P values of <.05 were considered to be statistically significant.

Results

Mean error rates by flanker condition are shown in figures 5 and 6. False negative rates were lowest with normal cell distractors (14.9%) and highest when abnormal cells were presented as distractors (17.4%), but the differences across flanker types were not significant ($F(3,90)=1.10$, $P=.35$). False positive rates were relatively high (47.5%, 49.4%, 47.8% and 48.0% for flanker control, text, normal cells and abnormal cells, respectively), but again there was little difference between flanker conditions ($F(3,90)=.26$, $P=.86$).

Figure 5 here

Figure 6 here

Receiver operating characteristic (ROC) and signal detection analyses were performed to check whether the marginal differences in error rates across flanker conditions resulted from a change in participants' cell discrimination abilities or whether they were related to a shift in decision criterion. Briefly, area under the ROC curve (AUC) measured participants' ability to discriminate abnormal and normal cells under each flanker condition, and was calculated from the confidence rating data using *SPSS* software. By contrast, decision criterion is an objective measure of participants' tendency to report the presence of an abnormal cell in conditions of uncertainty, and was calculated from true positive and false positive rate for each condition using a standard formula.[11] The results in figure 7 show no obvious differences across flanker conditions and this was confirmed statistically for both AUC ($F(3,90)=1.40$, $P=.25$) and criterion ($F(2.42,72.54)=0.75$, $P=.50$).

Figure 7 here

Discussion

The motivation for the present study arose from a concern that the relatively narrow viewing angle in virtual microscopy might increase susceptibility to distraction from peripheral visual stimuli, with consequent adverse effects on diagnostic accuracy. The results showed that visual flankers did not adversely affect the accuracy with which cytology novices were able to categorise cells in a virtual microscopy task.

Plausible explanations for the observed results are considered under the following headings.

Visual attention is narrowly focused during microscopy tasks

The virtual microscopy workstations used in the present experiment were assembled and positioned as they might be found in a typical cytology reading room. Consequently, the visual angle (69^{o}) between the focal stimulus and flanker stimuli was considerably larger than those normally employed in experiments of this sort (typically 1-2^{o}).[12,13] It seems intuitive to suppose that the visual angle between target and flanker stimuli in the present experiment was simply too great for visual distraction to occur. Our intuition is supported by the existence of a well described phenomenon in the psychophysics research known as Bouma's law.[14] Bouma and many other investigators have found that the accuracy of target identification increases with target-flanker separation.[15-17] Specifically, a critical spacing exists between objects below which visual crowding impedes target recognition. Bouma's constant is the ratio of target-flanker separation to target eccentricity and is widely reported to lie in the range 0.4-0.5.[16] In simple terms this would mean that objects located at an eccentricity of, say, 10^{o} require target-flanker separation of at least 5^{o} to avoid visual crowding. Smaller eccentricities will permit closer proximity of flankers to targets without interfering with target identification. Target eccentricity was very low in the present experiment (targets were presented close to foveal vison), and so we can surmise that the relatively large target-flanker separation suppressed any visual crowding effects. Furthermore, the presentation of targets and flankers on separate monitors is likely to have resulted in their perceptual ungrouping, thus reducing the effects of visual crowding still further. Such target-flanker configuration effects have been noted by others.[18,19] Finally, studies have demonstrated that cueing the location of a target, as was done in the current experiment, reduces the effects of crowding via attentional mechanisms.[20]

One might question whether the suppression of visual crowding was dominated either by the lateral distance between the target and flanker screens (distance AB in figure 4), or by their frontal (i.e. depth) separation (distance CD in figure 4). This is a question of potential relevance to the design of cytology reading rooms, but one that can only be answered through further systematic evaluation of the these two contributors to angular separation. In the meantime, the results presented here provide some reassurance that the visual angle that normally produces interference from peripheral stimuli is far smaller than that experienced in a typical cytology reading room.

The high perceptual load of cell images blocks flanker interference

A large body of behavioural and neurophysiological data supports the idea that perceptually demanding (i.e. difficult) tasks effectively block the processing of visual distractors.[21-26] Perceptual Load Theory proposes that an attentional filtering mechanism blocks or attenuates distractor processing under conditions of high perceptual load, but permits distractor interference when target processing is undemanding.[27,28] The results of the present experiment support the notion that cell interpretation is a perceptually demanding task that leaves little spare attentional resources to permit distractor processing.

Distractors are noticed but efficiently rejected

We must also consider the possibility that the flanker stimuli used in this experiment did in fact capture participants' attention, but were rejected at the decisional stage because of their irrelevance to the focal task. Supporting this idea is a considerable body of behavioural and neural evidence showing that stimuli appearing abruptly in visual displays (as in the current experiment) attract attention with high priority.[29-33] Once attended, they may,[34,35] but more usually do not[36-39] override an observer's intentions.

In conclusion, the robust finding that irrelevant visual flankers are largely ignored when attending to a virtual microscopy task is reassuring to aficionados of this relatively new diagnostic technology. However, it is important to point out that the apparent immunity to distraction demonstrated by participants in the present investigation does not constitute evidence that distraction does not exist in the cytology reading room. The necessarily restricted range of flanker conditions investigated here almost certainly do not represent the full array of viewing conditions in practice. Additionally, the possibility that experienced practitioners respond differently to distractors than novices cannot be completely excluded. Finally, we are currently investigating the effect of music and other forms of auditory distraction on diagnostic performance in cytology.

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