

RAD4160 – Psychophysics of Vision Essay

“The Eye as a Receptor.”

Introduction

The visual system allows humans to see the outside world.¹ In medical imaging, radiologists are the ones who perceive and interpret medical images, making eyesight crucial. They are tasked to identify abnormalities and to make a diagnosis.² As the eye ages, visual acuity also decreases.³ Similarly, long hours spent viewing images, also contributes to visual deterioration.² Thus, it is important that radiologists maintain optimal vision to achieve accurate results when interpreting images.²

Vision Anatomy

The human eye is an extremely complex organ.⁴ The anatomy is shown in Figure 1, and consists of three distinct regions.^{4, 5} The outer layer houses the cornea, the middle layer includes the iris and pupil, and the inner layer consists of the retina.^{4, 5} Vision begins with the cornea, where it transmits and refracts light onto the lens of the eye, and then onto the retina.^{1, 4} The iris then controls the amount of light reaching the retina, by adjusting the size of the pupil.^{1, 4} Once light reaches the retina, neurons convert the light into neural impulses, and processes this information.^{1, 4} This information then travels to the visual areas within the cerebral cortex to allow the brain to interpret the image.^{1, 4}

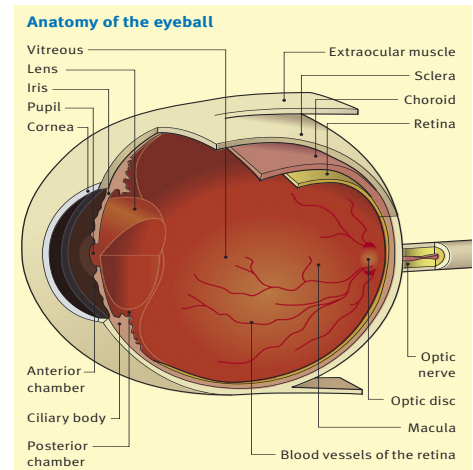


Figure 1: Anatomy of the eyeball (Presland & Myatt, 2010)

The Retina

The retina plays an integral role in vision because it consists of light sensitive photoreceptors.⁵ Photoreceptors detect and convert light into impulses, which are then transmitted to the visual cortex.⁵ These photoreceptors are made up of rods and cones, where rods are more abundant than cones.^{4, 5} Rods are activated and sensitive in low light settings, and are mostly located around the periphery of the retina, which is responsible for peripheral vision.^{4, 6} In contrast, cones are responsible for colour vision, and are located centrally near the macula.⁴ The centre of the macula is known as the fovea, and this is where the sharpest central vision is achieved.^{4, 5} In particular, the foveola, at the bottom of the fovea, has the largest concentration of cones.^{4, 5} However, a blind spot occurs on the retina because of no photoreceptors, and this is where the optic nerve enters the eye.⁵

Age and Visual Deterioration

Visual acuity refers to the spatial resolving capacity of the eye.⁷ As an individual ages, the functional abilities of the eyes decline and this affects the cornea, lens and retina.⁸ As time passes, corneal changes are evident, as the physical shape and optical properties change.⁸ This results in alterations in refraction and astigmatism.⁸ Similarly, changes in the lens affects vision because it becomes more selective, and absorbs more blue light.⁸ This causes decreased transmission of blue light and causes blue blindness.⁸ This would affect radiologists, because LCD and CRT monitors are used to interpret images. As both these screens emit blue light, if radiologists had blue blindness, the accuracy of diagnoses would be decreased, because their vision would be affected. This would also shift objects to appear more yellow in colour as well.⁸ Moreover, as the retina ages, visual acuity, visual field sensitivity, and contrast sensitivity, all decline in performance, and dark adaption threshold increases.⁸ This is likely a result of changes in the neuronal elements of the visual system, and changes in the ocular media as well.⁸ Neuronal changes include, decreased ganglion cells, photoreceptors and optic nerve axons.⁸ Additionally, visual acuity depends on cones.⁹

In medical imaging, radiologists should maintain good eyesight and have their eyes tested regularly to ensure accuracy when reporting on medical images. As radiologists spend long hours in front of computer monitors, dry eyes, eyestrains and myopia can occur.^{2, 12} Taking

frequent breaks and limiting the time spent in front of computer screens, can help alleviate these symptoms temporarily, and allow the reader to continue working.¹² Also, astigmatism and presbyopia can affect a radiologists vision as well. This is because astigmatism results in blurred vision, which could cause the edges of anatomy to be not defined. If abnormalities blended in with surrounding tissues, this could affect the identification of lesions such as those either on the chest wall, or adjacent to the chest wall. Thus, to help maintain good vision, regular eye tests with refraction examinations should be performed.^{8, 13, 14} Eye tests once a year, or when radiologists notice a change in their vision, allows optimal eyesight to be maintained. Visual correction aids can also be worn to combat against astigmatism, presbyopia and myopia to improve overall vision.¹⁵

Sleep deprivation also has a negative impact on a radiologists visual function as well.¹⁶ As this can occur following a night shift or being on call, it is essential that adequate sleep is achieved to ensure that visual function is not impaired.¹⁶

Radiologists also rely on contrast sensitivity to help differentiate between grey scales in images, such as fat and fluid densities.² This is because, contrast sensitivity refers to the threshold required to see a feature reliably.¹⁷ Moreover, decreased visual acuity leads to a significant increase in the threshold contrast needed to identify high frequency information (>2line-pairs/millimeter), such as micro-calcifications on mammograms.^{14, 15} As there is an established link between contrast and spatial resolution for detection of high frequency information,^{14, 15} the modulation transfer function (MTF) is related as well. This is because the MTF is a measure of the spatial resolution response of a system. Thus, if a radiologist had poor contrast sensitivity, these micro-calcifications could be missed. To assess contrast sensitivity, contrast sensitivity testing charts, such as the high and low contrast Bailey-Lovie charts or the Pelli-Robson chart, should be used.^{14, 18} For the Pelli-Robson chart, the letters change in contrast from different shades of grey, instead of changing in size.¹⁴ These allow differences between grey scale levels to be seen, and provides more information on low and intermediate spatial frequency defects.¹⁴

Cataracts in radiologists can also occur, due to the ionizing radiation received during interventional procedures, affecting the lens of the eye.¹⁴ As the lens is one of the most radiosensitive tissues in the body, opacities may form and lead to visual impairment.¹⁴ This affects high spatial frequencies, but posterior sub-capsular cataracts can also cause earlier loss of contrast sensitivity at lower spatial frequencies as well.¹⁴

The accuracy of diagnoses made by radiologists can be measured by signal detection theory (SDT), sensitivity and specificity. SDT provides a quantitative description of a reader's decision making and can be applied to interpreting images.¹⁹ The two aspects involved are discrimination and criterion.¹⁹ Discrimination refers to the readers ability to detect normal from abnormal, whereas, criterion refers to the under or overcalling of abnormalities.¹⁹ Both concepts are shown in Figures 4 and 5, and are independent of each other.¹⁹ For novice radiologists, a smaller discrimination is achieved because it is harder for them to differentiate between normal and abnormal radiographs.¹⁹ In contrast, experienced radiologists have a larger discrimination.¹⁹

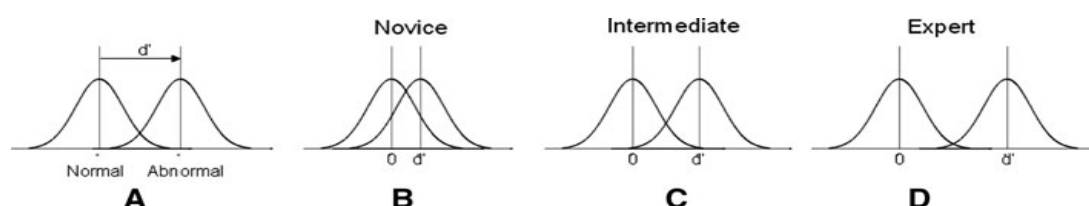


Figure 4: SDT parameter of Discrimination. Image A represents an equal variance signal detection model, where the left curve represents normal, and the right curve represents abnormal. Discrimination (d') is the distance between the two means of the curves. As a reader moves from a novice to expert reader, discrimination increases and the overlap between the two curves decreases. This is due to expert readers being better at identifying between normal and abnormal images, and this is shown in Image D.

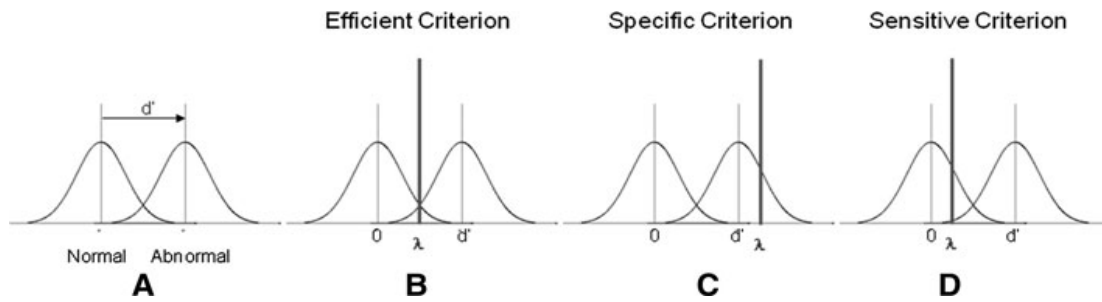


Figure 5: SDT parameter of Criterion. Image B shows a criterion set at a level that maximizes the accuracy achievable. If the criterion was set higher (Image c), this allows a specific criterion to be set, which increases the bias towards normal over abnormal. This increases the rates of false negatives, and decreases accuracy. If a low criterion was set (Image D), this produces a highly sensitive criterion, and this increases the bias towards calling images abnormal over normal. This would increase the rate of false positives and decrease accuracy once again. It should be noted that there is no correct set position for criterion, as this parameter varies. Criterion affects the outcome and the rate of false positives and negatives, but does not affect the decision making process. [Source: (Boutis et al., 2010)]

SDT is also based on sensitivity and specificity, where sensitivity refers to the ability to identify abnormalities and specificity refers to the ability to detect normal images.^{19, 20} Furthermore, a high criterion forgoes high specificity for low sensitivity, whilst the opposite occurs for a low criterion.¹⁹ The diagnostic accuracy for interpretations of images can be shown using a 2x2 table of sensitivity and specificity, and this is demonstrated in Table 1.²¹ Thus, SDT helps provide insight into the accuracy and performance of radiologists and where areas in reporting can be improved as well.

Table 1: 2x2 Table of Sensitivity and Specificity in terms of medical imaging. Sensitivity can be calculated by $TP/(TP+FN)$, and this represents the probability of detecting abnormalities when it is present. Specificity can be calculated by $TN/(TN+FP)$, and this represents the probability of detecting a normal image when it is normal.

RADIOLOGISTS INTERPRETATIONS	REAL IMAGING RESULTS	
	<i>Abnormal</i>	<i>Normal</i>
<i>Abnormal</i>	<u>True Positive (TP)</u> Abnormality detected by radiologist and abnormality seen on images	<u>False Positive (FP)</u> Abnormality reported by radiologist but NOT detected on image (normal images)
<i>Normal</i>	<u>False Negative (FN)</u> Normal radiologist reporting but abnormality present	<u>True Negative (TN)</u> Normal radiologist report and normal on images

Conclusion

As radiologists are tasked with detecting abnormalities on medical images, eyesight is crucial. With age, vision deteriorates, and radiologists can maintain optimal vision by taking regular breaks from computer screens and having their eyes tested regularly. This allows correct interpretations of images to be performed, and this performance can be measured by signal detection theory, sensitivity and specificity as well.

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