**Psychophysics of Vision: Measurement of Perceptual Ability As Applied to Medical Imaging – The Eye as a Receptor**

## Introduction

Vision plays an important role in the field of medical imaging. To understand this complex perceptual system, we adopt a method known as psychophysics, a branch of psychology which explores the link between physical stimuli and perceptual experience (Mather, 2009). The basic anatomy and physiology of the human visual system will be reviewed and the concept of visual perception will be introduced. Age is important to the function of the visual system and the issue of visual acuity decreasing with age will be discussed. The effects of visual perception and visual acuity will be correlated with medical imaging.

## Basic Anatomy & Physiology of the Human Visual System

The human visual system begins with the eye, an organ responsible for the detection and evaluation of light. Its major components are illustrated in Figure 1. At the back of the eye, the cells in the retina are ordered in a laminar fashion and there are three layers: ganglion cells, bipolar cells and photoreceptors (Figure 2). Photoreceptors are responsible for the transduction of photochemical energy into neural signals. No photoreceptors are present at the optic disk, where the optic nerve fibres leave the retina. There are two classes of photoreceptors: rods and cones (Bear et al., 2001).

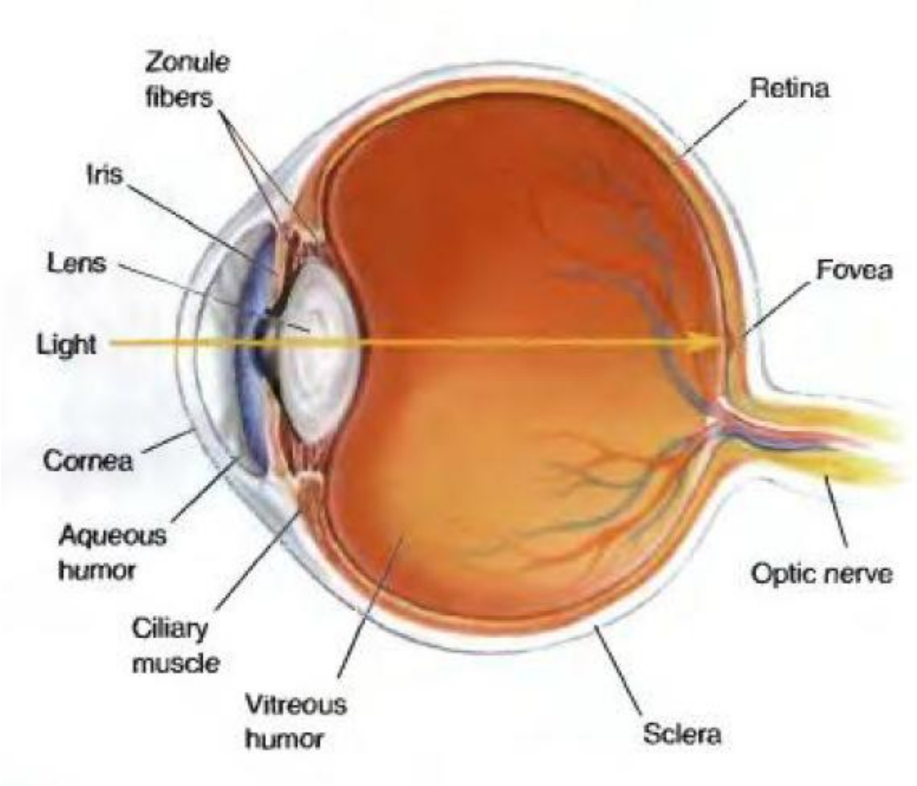



Figure 1: A cross-sectional view of the human eye (Bear et al., 2001)

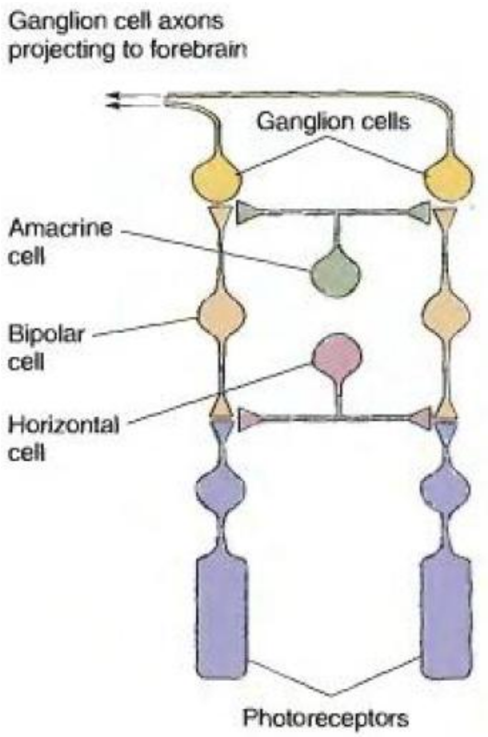



Figure 2: A basic representation of the cells of the retina (Bear et al., 2001)

Rods contain a higher photopigment concentration, making them much more light-sensitive than cones and they function in dark conditions. Cones come in three different types (red, green and blue) and as they contain a different pigment, each cone is sensitive to different wavelengths of light (Wade and Swanston, 2001). Cones allow us to see colour and only function in daylight as high-resolution vision is required with numerous ganglion cells. This occurs at the fovea where there are no rods present, only cones (Figure 3). Here, the ganglion cells are displaced, allowing the light to pass directly to the photoreceptors.

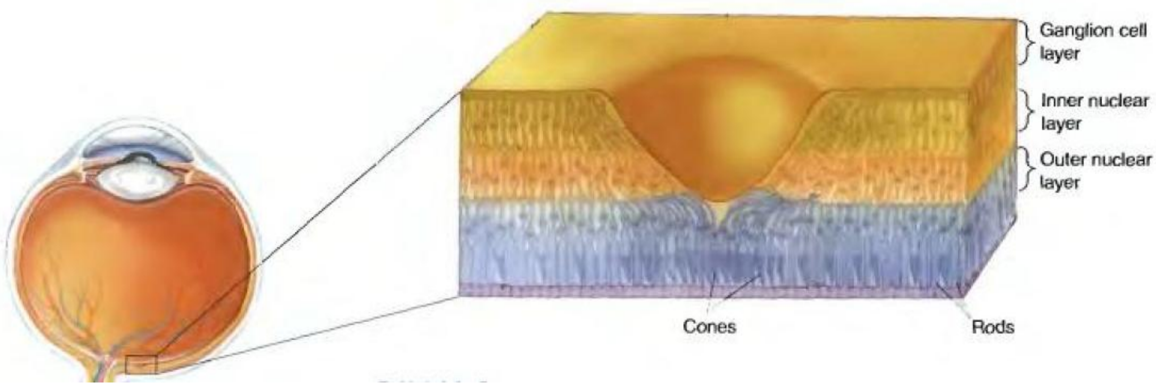



Figure 3: A cross-sectional view of the fovea (Bear et al., 2001)

The eye's sensitivity to light varies according to different lighting environments. Dark adaptation occurs when the sensitivity to light increases greatly to accommodate for darker environments by the use of rods. Temporary saturation of the rods will occur when moving from a dark to a bright environment (Bear et al., 2001). Light adaptation takes over to reverse the retinal changes which occurred in dark adaptation and the cones adapt more easily (Mather, 2009). The phenomena of dark and light adaptation enable the human visual system to function in a broad range of light intensities (Bear et al., 2001).

Information about light is transmitted from the photoreceptors to bipolar cells to ganglion cells. Axons of the ganglion cells form the optic nerve and travel through the optic chiasm and optic tract, before most of the axons form synapses with the lateral geniculate nucleus (LGN) of the thalamus. The neurons in the LGN are then projected to the primary visual cortex (also called area 17, V1, or striate cortex) via the optic radiation (Figure 4). This path controls visual perception because any lesions located in the pathway from the eye to the primary visual cortex will result in blindness (Bear et al., 2001).

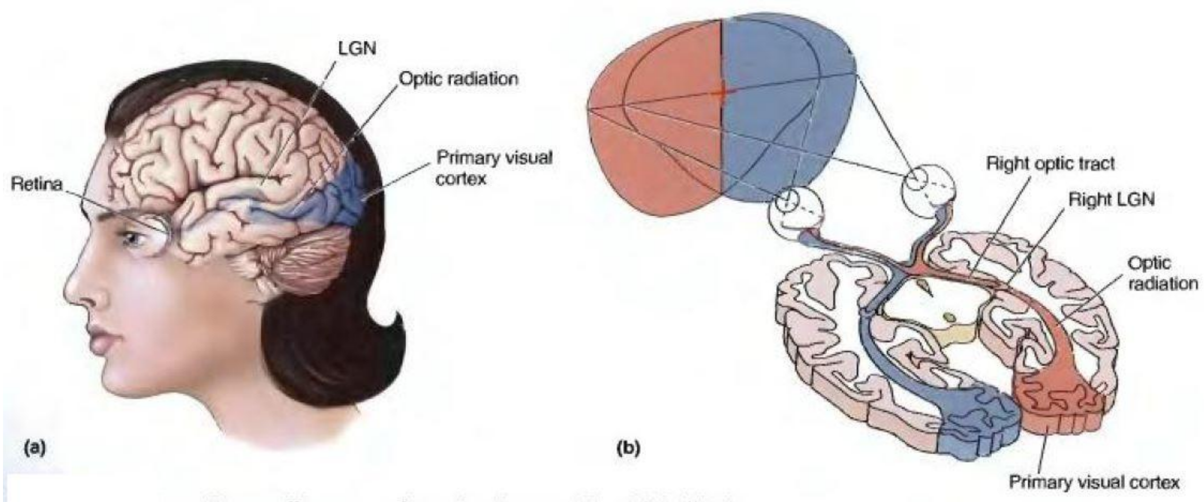



Figure 4: The visual pathway which demonstrates conscious visual perception. (a) Side view of the visual pathway in profile and (b) Transverse view of the visual pathway (Bear et al., 2001)

**Visual Perception**

Visual perception incorporates three constituents: depth perception, form perception and attention. Depth perception is the process of determining an object's location through the analysis of depth cues and there are two types: monocular and binocular. Monocular cues (one eye) may include (Mather, 2009):

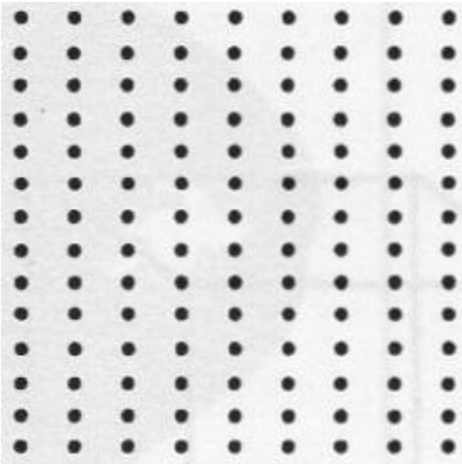
- Retinal image size: an object with a steady size will be gradually seen by the retina as getting smaller when viewed from various distances
- Texture gradients: provides visual information about surface orientation and depth based on element size, shape and thickness
- Motion parallax: occurs due to objects moving at different distances from the viewer (i.e. nearer objects move faster than those further away)
- Height in the visual field and image blur
- Atmospheric perspective and accommodation
- Shadows and interposition

Binocular cues (two eyes) include two types: vergence (nonvisual) and binocular disparity (visual). Vergence specifies the angle created by two visual axes, presenting distance information. Binocular disparities transpire due to the slightly different positions of the eyes which result in slightly different visual perspectives. Multiple cues are combined to give quantitative information (Mather, 2009)

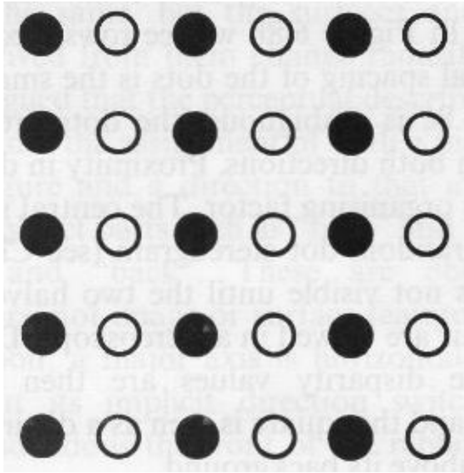
Form perception develops in four stages: elementary feature detection, perceptual segregation, perceptual components and pattern recognition. Initially, we must identify the elementary features of an image, such as curves, line or colours. Perceptual segregation is the process of separating an image into smaller parts to allow detailed processing (McConnell, 2013). Perceptual components of an image can be grouped together, based on a number of properties as defined by the Gestalt laws. These properties are (Mather, 2009):

- Proximity: two adjacent points of an image are likely to be grouped together
- Similarity: image sections are grouped together based on a similar visual texture such as colour and size
- Good continuation: contours which run smoothly instead of sharply are grouped together
- Common fate: where grouping occurs due to common movement characteristics

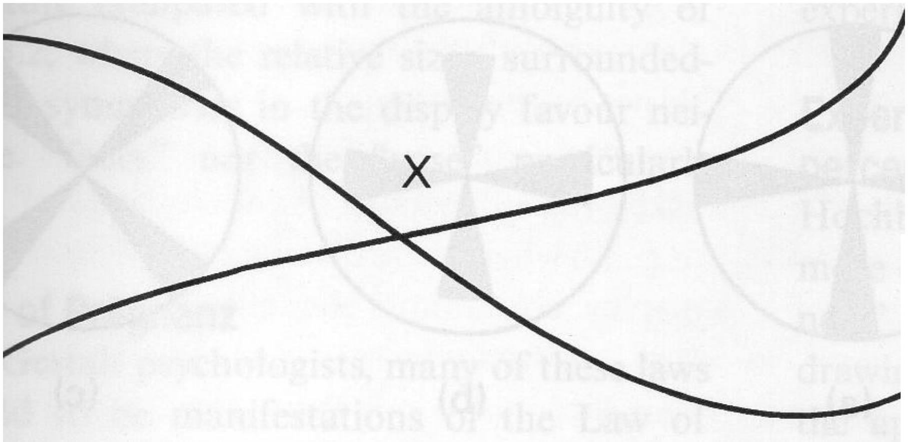
Bruce et al. (2003) also mention the property of closure where the visual system will add missing parts to an image for completion. These properties are illustrated below (Figure 5):



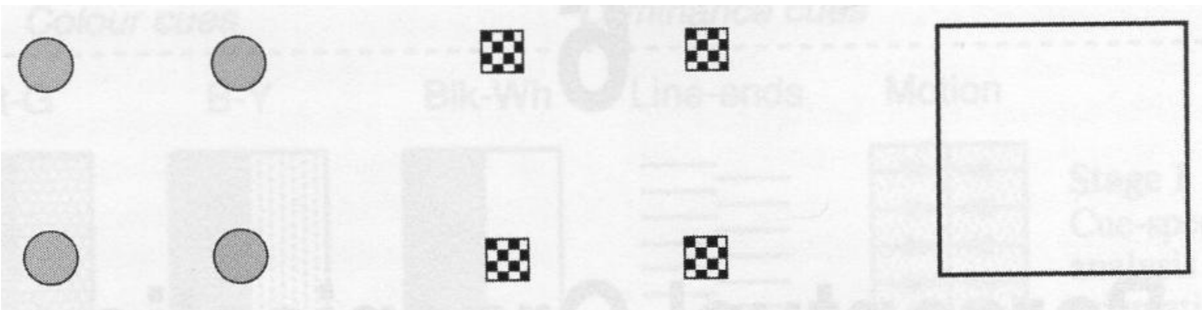
(a) Proximity: dots are grouped based on their location



(b) Similarity: dots are grouped as columns based on their similarity in colour




(c) Good continuation: this is seen as two smooth lines which intersect at X, instead of two V-shapes



(d) Closure: the first two patterns are seen as squares, instead of crosses

Figure 5: A visual representation of the Gestalt Laws illustrating the properties of (a) proximity, (b) similarity, (c) good continuation and (d) closure (Bruce et al., 2003)

Pattern recognition determines the correlation of the structure with memory until a match is established. An analysis of the relationship between different parts occur involving only basic geometric shapes (also known as geons), originally modelled by Biederman in 1987. Figure 6 shows the combination of Biederman's geons to form objects. Two forms of processing exist where bottom-up processing is the use of incoming information and top-down processing is the use of knowledge. Bidirectional activation (both bottom-up and top-down processing) occurs in humans (Figure 7).

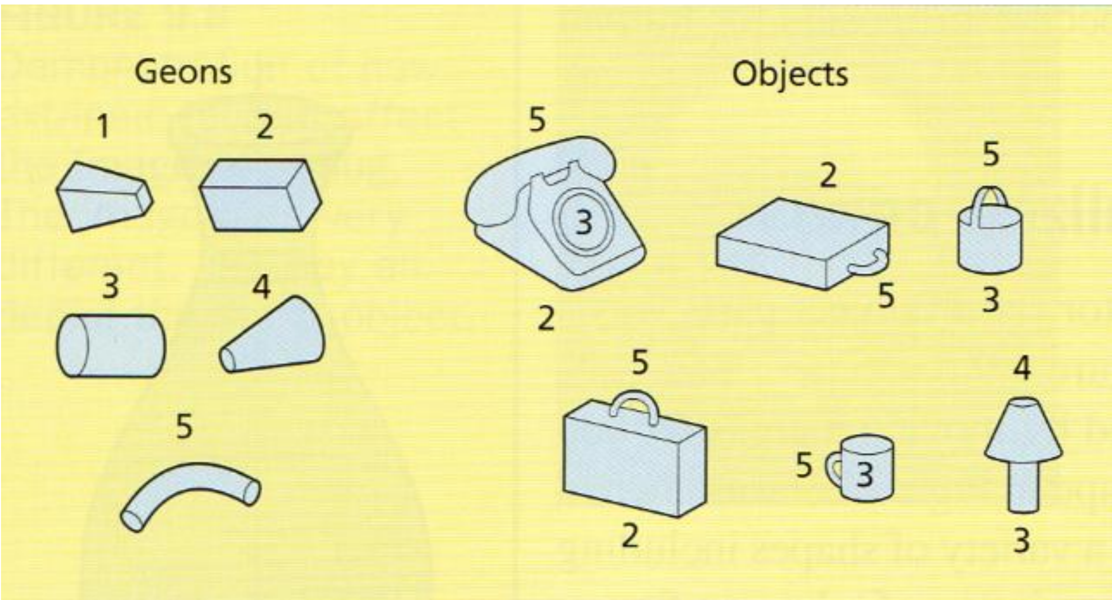



Figure 6: Biederman's geons and combining them to form objects (Mather, 2009)

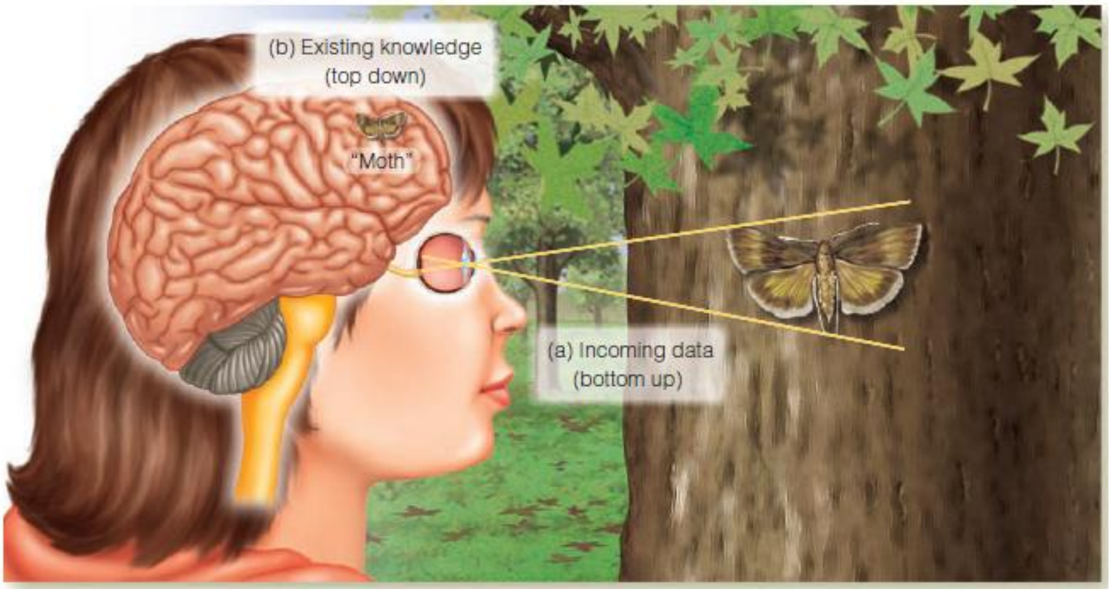



Figure 7: The difference between bottom-up and top-down processing (Goldstein, 2010)

Selective attention is the technique of concentrating on specific objects whilst ignoring others. This can be achieved through eye movements where we aim our fovea at something of interest to mentally review it. The main purpose of attention is to discern the most important parts of an image for further processing. Central selective processes also play a role in attention where information can be collected from parts of an image where we are not actively focusing our attention (Goldstein, 2010).

Though not often appreciated, perception is widely used in medical imaging. Unfortunately, many radiologists have foolishly assumed that what they perceive in images is an accurate representation of what truly has been imaged and perception is ignored unless it fails. Perceptual errors do occur which has led to the research of perception in medical imaging (Kundel, 2006). Our awareness of the extremely complex task that radiologists undertake during the diagnosis of clinical images has expanded since research in this area began 60 years ago (Krupinski, 2011). Depth perception is used in three-dimensional imaging, such as CT and MRI to analyse sectional anatomy and possible pathology. Form perception is essential when evaluating anatomical structures for assessment based on proximity and similarity. Attention is imperative to the diagnosis of pathologies. When examining an image, the radiologist will pay specific attention to unusual appearances.

**Visual Acuity and Aging**

Human vision degenerates with old age. A number of conditions account for this (Mather, 2009):

- Pupillary miosis: the pupil does not move as much in the elderly, resulting in poor illumination
- Presbyopia: the elasticity of the lens declines with age, causing decreased accommodation and long-sightedness
- Senile cataracts: the lens increases light absorption
- Macular degeneration: deterioration of the central retina

Visual acuity decreases with old age and in medical imaging, this negatively affects the reading of images. Psychophysical methods are employed to measure the performance of the eye and these tests are of a perceptual, rather than an optical, nature. Vision is conveyed in terms of acuity, the capacity to distinguish features. These tests are illustrated in Figure 8 and include:

- Vernier acuity: recognising misalignment of two lines
- Identifying a single line
- Measuring the smallest separation between two lines
- Grating acuity: a grating with a specific spacing is to be distinguished from the uniform grey field with minimum contrast
- Snellen charts: alphabets of decreasing size tests the eye's capability to separate each letter
- Landolt C charts: uses a pattern with a black ring and a section missing like a 'C' and the observer is asked to identify the missing section in varying positions

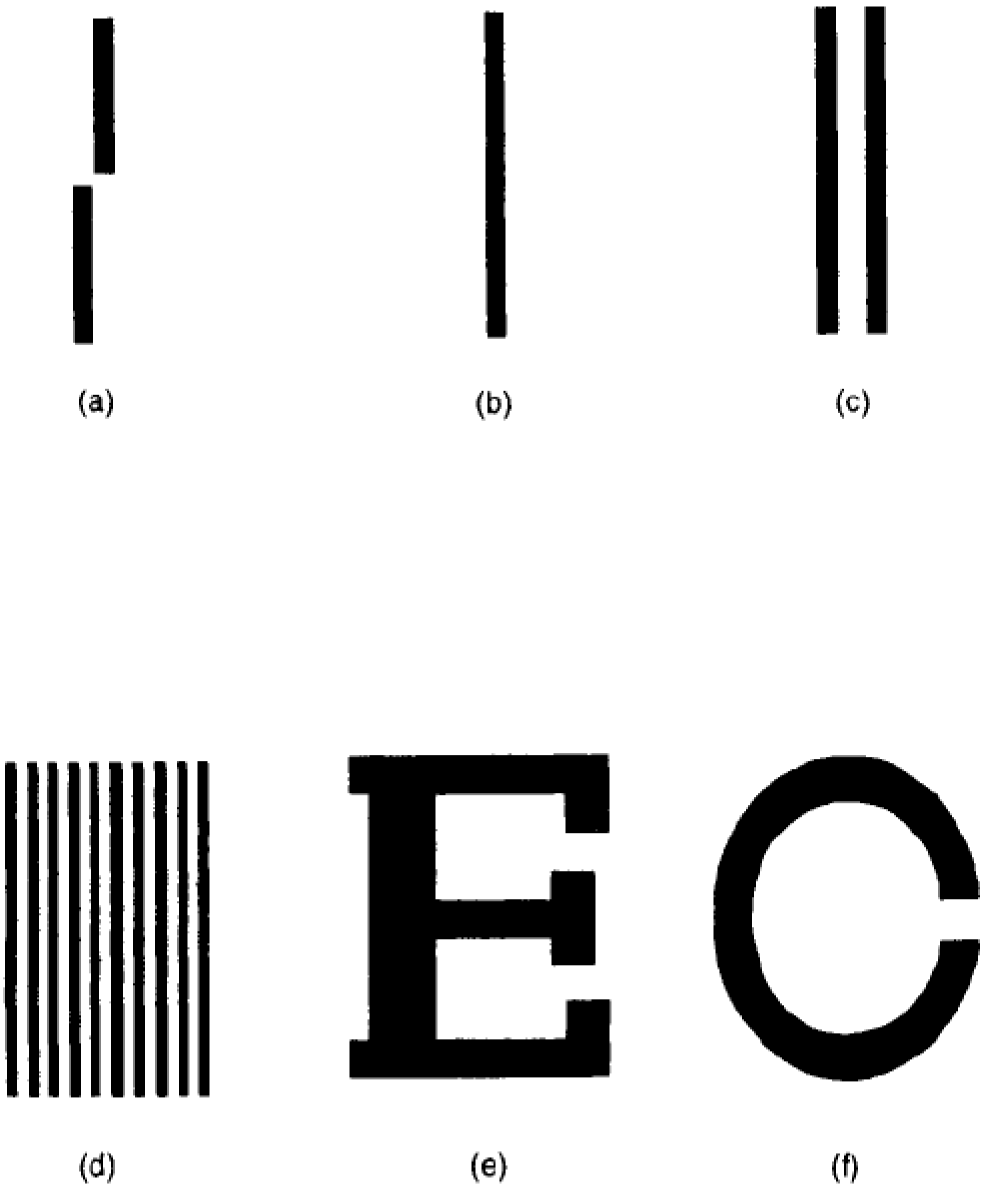



Figure 8: Different examples of tests on visual acuity, (a) Vernier acuity, (b) identifying a single line, (c) two-line discrimination, (d) grating acuity, (e) Snellen charts and (f) Landolt C charts (Wade and Swanston, 2001)

Although vision is the vital sense in the field of medical imaging, inadequate attention has been paid to the visual health and ability of the radiologists. Individual differences in radiologist performance begin with vision, but there is no satisfactory quality control in place (Safdar et al., 2009). To account for the decreased visual acuity usually associated with age, a standard of visual acuity should be set for radiologists. This should include: regular routine eye examinations, visual acuity tests and contrast sensitivity tests (Straub et al., 1991). An ethical concern such as the issue of public safety arises where radiologists have a duty of care to the patient to ensure the most accurate diagnosis of their condition. Wong et al. (2010) reviewed two separate groups of radiologists regarding their view on regular visual tests for their profession. The majority of the radiologists surveyed agreed that adequate visual function is crucial to medical imaging (Wong et al., 2010).

## Conclusion

The human visual system is an intricate system which houses the eye as a receptor. Visual perception is an inherent component of the image interpretation process, but is not widely perceived as such. Further research is needed to analyse the role of perception in medical imaging to enhance radiologists' expertise in evaluating images. A standard of visual acuity and overall ocular health should be compulsory for all radiologists and those who are entering the profession to ensure accurate diagnoses and reporting.

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