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CPD CODE: C-111357

MCQs AVAILABLE ONLINE: Tuesday 1 April 2025

CLOSING DATE: Sunday 8 July 2025

ANSWERS PUBLISHED: September 2025

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CPD CODE: C-111357

Exploring visual field perception

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Visual field testing, or perimetry, is a well-established element of sight testing in a typical optical practice, allowing for the assessment of the extent and function of an individual's field of view (FoV). Whilst these assessments correlate well with the function of the photoreceptors and visual pathway processing, the world we experience across our field of view seems far more 'perfect' than our visual physiology first suggests. In addition, our visual fields may not accurately reflect the portions of our visual environment that we are *consciously* aware of at any one time.

This article will discuss both the physiological and cognitive aspects of visual field function – and highlight the importance of higher visual processing that marries both aspects for a resultant visual experience.

PHOTORECEPTOR PHYSIOLOGY AND ORGANISATION

The typical normal visual field, when the eyes are in the primary gaze position, extends from 100° temporally to 60° nasally in the horizontal meridian, and between 60° superiorly and 70° inferiorly[1]. Obvious anatomical features, such as the nose and brows, will impede the extent of the visual field, as will certain ocular and neural pathologies. To allow detection of any distal stimulus on our visual field, the retina is home to approximately 126 million photoreceptors[2,3]. Whilst, at first glance, this seems an impressive number of photoreceptors in comparison to commercial camera sensors, it is important to bear in mind that the type, density and neural convergence of the photoreceptors is not consistent across the retina.

Neural convergence represents the number of photoreceptors connected with each ganglion cell axon leaving the eye via the optic nerve; the higher the neural convergence, the greater the number of photoreceptors that are pooling their outputs to one axon[2]. Ideally, for the highest resolution, and to reduce the loss of visual information, a one-to-one photoreceptor to axon ratio would be desirable[4] (i.e. no neural convergence). However, this would mean that instead of the optic nerve currently being comprised of approximately one million axons[5], it would need to contain 126 million axons. If this were the case, it is suggested that our brains would have to be considerably larger[6,7] to facilitate the additional axons and subsequent visual processing. Thus, our visual processing system has evolved to compress visual information from the retina to help with space and processing efficiency, while still allowing a good level of acuity where we require it.

Cone photoreceptors dominate our foveal vision, with a high concentration of densely packed cone cells located at the fovea. Although the foveal region represents less than one percent of the surface area of the retina, processing from this region is represented in eight to 10 per cent of the visual cortex[2,6,8]. This **cortical magnification** is, in part, due to the low levels of neural convergence; typically, between one and six foveal cone photoreceptors are connected with each nerve axon leaving the eye[2] (with one-to-one cone photoreceptor-to-axon connection observed among foveal cone photoreceptors)[9]. In comparison, rod photoreceptors show high levels of neural convergence, with an average of 120 rod photoreceptors to one axon[2]. This bias in the visual pathway towards the foveal photoreceptors, and the higher density of foveal receptors[2,7,9], results in a foveal visual field in which we experience the highest visual acuity.

Moving peripherally away from the fovea, the cone cells rapidly give way to rod photoreceptors. The human eye contains approximately 120 million rod photoreceptors[2,3], which typically have extremely high levels of neural convergence compared to cone cells. Whilst helping to increase detection of light and motion in the peripheral FoV, this comes with a sacrifice of spatial resolution[4]. Thus, detailed vision beyond ~5° from fixation is typically poor[10,11], and object discrimination is more adversely affected by visual crowding of stimuli in the periphery[9,12,13].

This may come as a surprise considering that the visual environment that we perceive in our day-to-day experience seems perfect across the FoV, but we can simply demonstrate the poor peripheral performance in the visual system with a simple demonstration: keeping your eye fixated on one of the printed words in this sentence, attempt to read the subsequent printed words without changing your fixation. You will probably find that you may only be able to cognitively perceive two or three neighbouring words before being unable to read any further.

Our cone photoreceptors are generally divided into three types that are more sensitive to short, medium and long wavelengths of light[2], whereas rod photoreceptors typically contribute to achromatic (colourless) visual processing (although some contribution to colour perception by rod cells has been noted in mesopic lighting conditions[14,15]).

The prevalence of rod photoreceptors in the periphery, and the rapid reduction in cone-cell density, suggests that we should experience limited perception of colour in our peripheral vision, but again this clearly goes against our everyday experience[11].

Try this experiment: ask a test subject to fixate on a distant target, then slowly bring a pen with a coloured top into the subject's FoV. When they first see the pen in their FoV, ask for the colour of the top at this point; typically, they will not be able to definitively identify the colour[10]. As the pen is moved more towards the central field of view (and the light from the pen falls on a greater number of cone cells), the subject should be able to identify the colour.

THE VISUAL EXPERIENCE

So, while we appear to experience a flawless representation of our environment across the visual field[9], the reality is that much of our cognitive visual experience is a construct of higher-order visual processing that generates a stable internal model of our surroundings, based on the initial bottom-up signals from the retina.

To appreciate the capacity of our visual processing to create illusionary visual experiences, we can consider the blind spot. Due to the inverted nature of the photoreceptors in the human eye, the axons project anteriorly to the nerve-fibre layer and then leave the eye via the optic nerve. As there are no photoreceptors at the optic disc, any image formed at the optic disc will not be processed and we will be blind to any proximal stimulus in this area (approximately subtending 5-7° of the visual field[4,16]).

The term 'scotoma' is applied to any area of the visual field in which visual processing is absent or diminished; as the blind spot is anatomically normal, we can describe this as a **physiological scotoma**.

We are not conscious of the missing FoV associated with the blind spot for two reasons: firstly, the physiological scotomas of each eye do not overlap, so (assuming good binocular vision) any distal stimulus imaged on the optic disc of one eye will be seen by the other eye. Secondly, higher visual processing mechanisms attempt to 'fill in' the blind spot area based on the immediate surrounding stimuli[8,16].

Figure 1 elegantly demonstrates this. With the left eye closed and the right eye fixating on the cross, hold the figure at arm's length (keeping it horizontal) and slowly move it inwards. You should perceive the spot disappears at a certain distance when the retinal image position coincides with the optic disc.

Even though stimuli in the blind spot region will not be processed, what is perhaps more interesting is how our brain 'fills in' the scotoma by making an informed guess using elements in the surrounding scene (in the case of **Figure 1**, you do not simply see a blank area when the spot disappears, but typically the grid lines will be continuous across the scotoma).

This perceptual filling, using foveal visual processing, can also influence our perception of the peripheral FoV; **Figure 2** shows a version of the Uniformity Illusion. When you fixate at the centre of the scene for a few seconds, you will notice the peripheral visual perception starts to conform to the pattern presented at the foveal region[9]. Whilst this illusion is not present in our FoV for normal viewing conditions, it does demonstrate that there is interaction and extrapolation between the very anatomically different foveal and peripheral regions in visual processing.

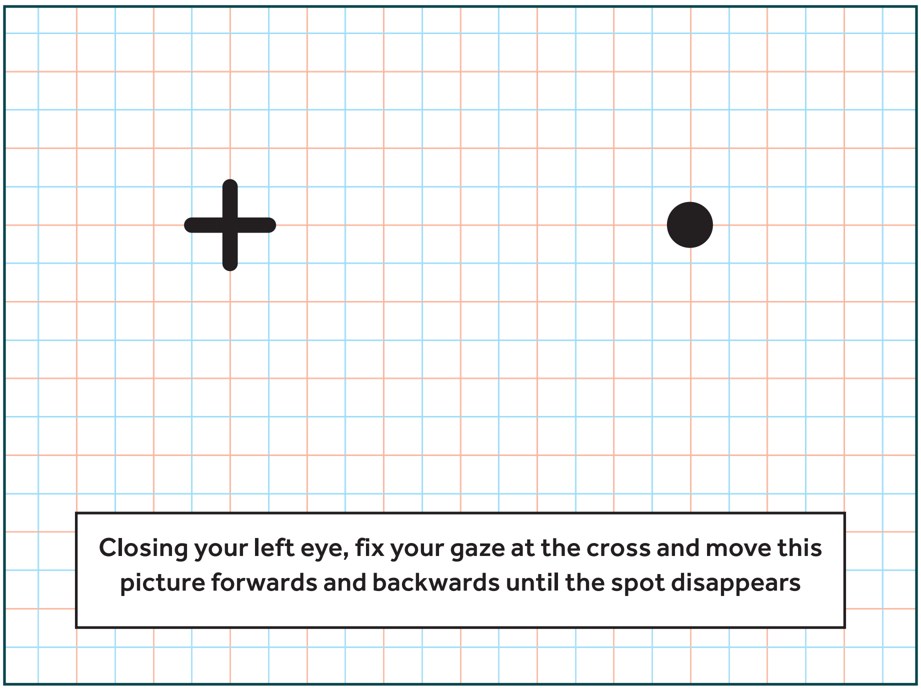

FIGURE 1: Demonstration for the existence of the blind spot

The cognitive ability to perceptually fill-in gaps in our visual field is useful in relation to the blind spot, though this can potentially mask some pathological scotomas with patients failing to recognise visual field loss. More extreme pathological field loss, such as hemianopia, will result in a cognitive contraction of a patient's visual field; the patient will not necessarily report a 'dark area' in the missing field, but rather they will not be conscious of any stimuli in the affected area[12] (although some research does indicate that some peripheral visual processing, sometimes referred to as 'blindsight' can be unconsciously processed through dorsal-stream and extra-striate processing[4,17,18]).

Many patients can be cognitively unaware of visual field loss, including gross field defects such as hemianopia[8], until they are examined with a perimetry (visual fields) test. This lack of perceptual awareness associated with visual scotoma, and even denial of any visual difficulties, is known as **visual anosognosia**[12]. Thus, as there may be no perceptual awareness of visual field loss, the importance of perimetry testing cannot be understated, especially for patients with neurological pathologies or trauma.

Gross peripheral field defects, such as hemianopia, can impact on a patient's ability to navigate around their environment. Despite the limitations of the peripheral FoV in relation to acuity, peripheral visual processing enables us to identify targets of interest within the visual field, especially when moving around the environment[10].

Salient stimuli in the visual field will inform the saccadic mechanisms of the eyes, allowing our eyes to move and **overtly attend** to the target with our more detailed foveal vision. This enables the avoidance of obstacles as we move around our environment, and the detection of potential hazards or dangers within the peripheral field. The presence of pathologies that disrupt the function of gross peripheral vision may also be inferred by patients reporting incidences of falls, bumping into obstacles and car accidents[12]. Severe peripheral vision loss can even affect the ability to fluently read at speed, even when foveal vision may remain[12,19].

VIEWING IN THE PERIPHERY

Whilst we appear to have an ocular mechanism that will physiologically process information across a very wide FoV, the reality is that we are only consciously aware of certain areas of our FoV at any one time; this relates to higher-order processing that underpins our **attention** mechanism.

Visual attention can be **overt** or **covert**; overt attention (as mentioned above) is when you change your eyes' fixation to the desired object in the FoV[2,6,20,21], whereas covert attention is when you keep your eyes fixated at a point, but consciously pay attention to another stimuli in your FoV[2,20] (for example, you could be looking directly at someone, but also covertly attending an object to the side of the person).

Overt attention is our primary mechanism for gathering detailed information about objects and the environment; however, patients in practice may present with disrupted or missing central areas of macular vision (for example, patients with age-related macular degeneration). For such cases, we can use the above covert attention mechanisms and train the patient to use undamaged areas of their FoV beyond the fovea, known as **eccentric viewing** therapy. This has been shown to be moderately successful in many cases for near-vision tasks, though there is less evidence supporting the efficacy for distance eccentric viewing[22,23].

Patients who are eccentrically viewing stimuli will be using extra-foveal parts of the retina but, as discussed above, acuity rapidly diminishes beyond the fovea. It is suggested that letter sizes need to significantly increase, the further the stimulus is from the eye's fixation, in order to facilitate successful eccentric viewing strategies.

Snowden *et al* suggest that letter sizes should double for every 2.5° from foveal fixation to maintain legibility[2], whereas Rosenholtz suggest that letters should be four times the size at 10° off-fixation[13] (**Figure 3**). Thus, eccentric viewing therapy must consider magnification (including large font use), and steady-eye strategies (keeping the eye as stationary as possible and moving the reading text itself through undamaged regions in the peripheral FoV) to promote success alongside visual training and adaption.

See **Figure 3**; keep your eyes fixated on the red A at a working distance of 35cm, and attempt to make out the subsequent letters. This should be significantly easier for the bottom row of letters.

When the eye has dark-adapted in scotopic conditions, cone-cell function typically drops off resulting in a perceptual central relative scotoma[9]. Again, covert attention can be used in dark-adapted conditions to view desired areas of the

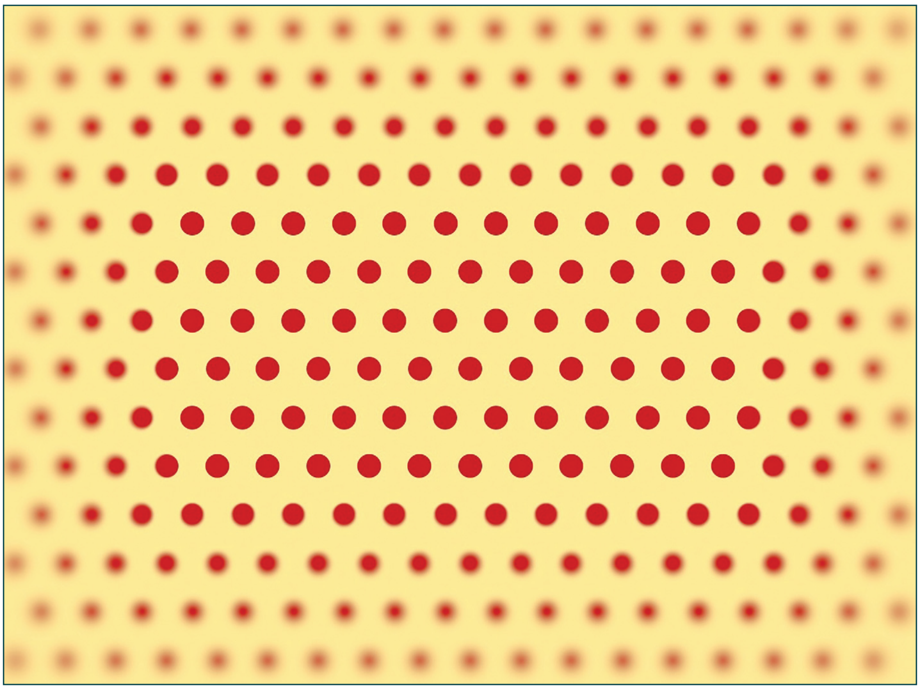

FIGURE 2: The Uniformity Illusion

environment by changing eye fixation and moving the stimuli's retinal image to the peripheral regions of the retina. Astronomers employ this technique when viewing faint objects through telescopes (known in astronomy as 'averted gaze').

INATTENTIONAL BLINDNESS AND ATTENTION

Even with normal physiological FoV, we are limited in how much we can **attend** to at one time. If our attention is concentrated on one specific area of our environment, we may not consciously process stimuli within other regions of our physiological FoV (even though the light from these peripheral stimuli is still striking the retina); this is known as **inattentional blindness**[2,24].

In addition, the size of the attentional FoV can be influenced by the viewer's concentration or distraction levels when performing various tasks, factors that directly affect attentional load[25,26]. For example, if a person is asked to intensely concentrate on a specific object in their FoV, inattentional blindness is more likely to occur in other parts of the peripheral visual field.

FIGURE 4: Inattentional blindness experiment[27]

Simon and Chabris effectively demonstrated inattentional blindness with a seminal experiment[27] presented as a video to test subjects (**Figure 4**). The subjects watched a video of a ball being thrown between players of two teams and were asked to count the number of passes between players. Upon questioning afterwards, it was found that more than 50 per cent of the subjects failed to notice a man in a gorilla suit, or a woman carrying a white umbrella, moving through the scene[27,28]. The concentration required in counting the passes in the video increased the attentional demand in the perceptual process, and this helped promote the chance of inattentional blindness observed in the results of this experiment.

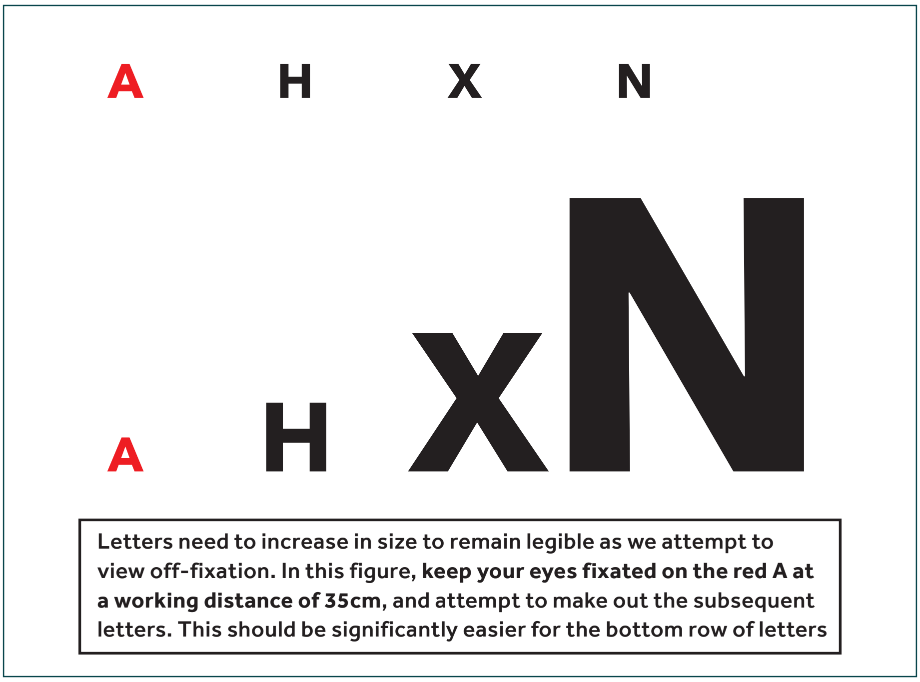

FIGURE 3: Letters need to increase in size to remain legible as we attempt to view off-fixation

Although inattentional blindness is considered an inherent cognitive disadvantage, it is taken advantage of by magicians. By focusing a spectator's attention to a specific area of the visual field, or by giving spectators a seemingly innocuous, but demanding, task to perform (such as shuffling a deck of cards), this can help draw a spectator's attention away from any subterfuge in other parts of the visual field[29].

Division of attention can also have more serious consequences. It is known that using mobile phones can increase the attentional load for a patient and result in a reduction of visual attention in other parts of the FoV, significantly increasing the chance of accidents[2]; needless to say, this rationalises the prohibition of mobile phone use whilst driving.

ASSESSING THE VISUAL FIELD

There are various types of perimetry tests available that can assess aspects of a patient's visual field. The most encountered in practice is **static** perimetry, which present multiple stimuli to the patient at fixed locations across the FoV and are commonly used for central visual field screening (approximately out to 30 degrees from the eye's fixation, though modern machines can adjust the test field extent).

Static perimetry can detect small scotomas in the visual field and can also help quantify the level of visual loss within the affected area if set to full-threshold assessment. **Kinetic** perimetry typically involves a stimulus that moves from a non-seeing to a seeing area of the visual field, with different sized and coloured stimuli used to quantify the levels of function; as such, kinetic perimetry is ideal to assess the extent of a patient's visual field. Small areas of scotoma can be difficult to detect accurately with kinetic methods, though gross field defects can be identified.

A very basic version of kinetic perimetry is the confrontation test, which can be used to quickly check for gross field loss. The practitioner stands face-to-face with the patient and advises the patient to close their left eye whilst the practitioner closes their right eye (much like pupillary measurement). With the patient fixating on the open eye of the practitioner, the practitioner will move a stimulus (i.e. fingers, or a 'bead on a stick'; see **Figure 5**), positioned in between the patient and practitioner, from non-seeing to seeing areas of the visual field along various meridians[30,31].

If the patient reports perceiving the stimuli later than the practitioner, this may indicate contraction and loss of peripheral field function. Changes to the stimulus, such as the size of the disc, or the number of fingers, could be utilised to provide some qualitative assessment of visual function. Of course, this is a very basic test and relies on the tester having normal visual fields.

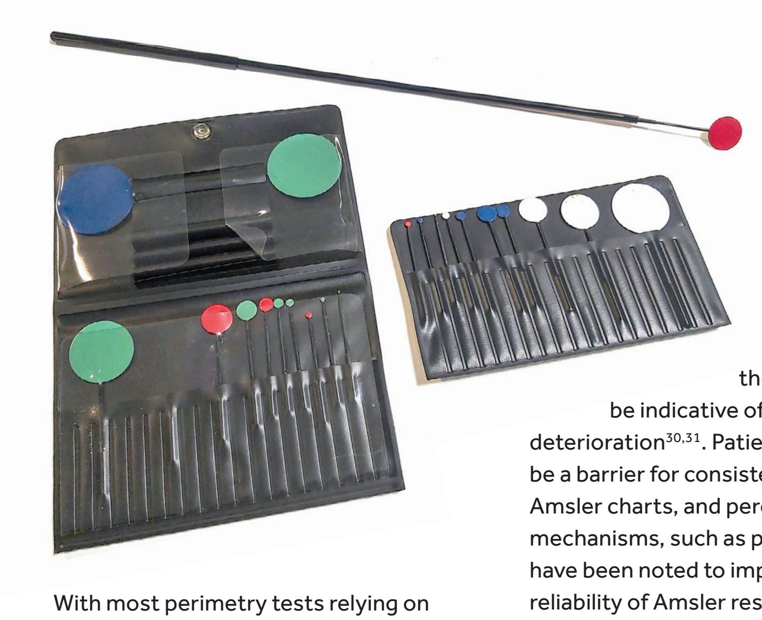

FIGURE 5: Variations in stimuli that can be used with manual kinetic perimetry

Amsler charts (**Figure 6**) can be used in practice, or as a patient self-administered perimetry test, to allow monitoring of the macular field (approximately 10˚ out from fixation). Patients reporting missing lines or distortions within the Amsler grid can be indicative of macular deterioration[30,31]. Patient compliance can be a barrier for consistent testing with Amsler charts, and perceptual mechanisms, such as perceptual filling, have been noted to impact on the reliability of Amsler results[30,32].

With most perimetry tests relying on subjective responses, a number of factors affect the reliability and validity of the results[32]. Patient reaction time can impede on reliability, especially with kinetic perimetry, and attentional mechanisms may impact on conscious perception of test stimuli if the patient is distracted. It is also noted that many perimetry tests have inherent learning-bias in the results, with many patients performing better when perimetry tests are repeated; this underpins the need for careful patient instruction and management when performing the initial test.

SUMMARY

Perimetry tests remain an important screening method for detection and monitoring of pathologies that disrupt visual function. A greater understanding of our perceptual mechanisms, and developments in objective perimetry tests, will certainly enable more reliable assessment of retinal function in the future, and increase awareness of attentional limitations when considering the patient's interaction with the visual environment.

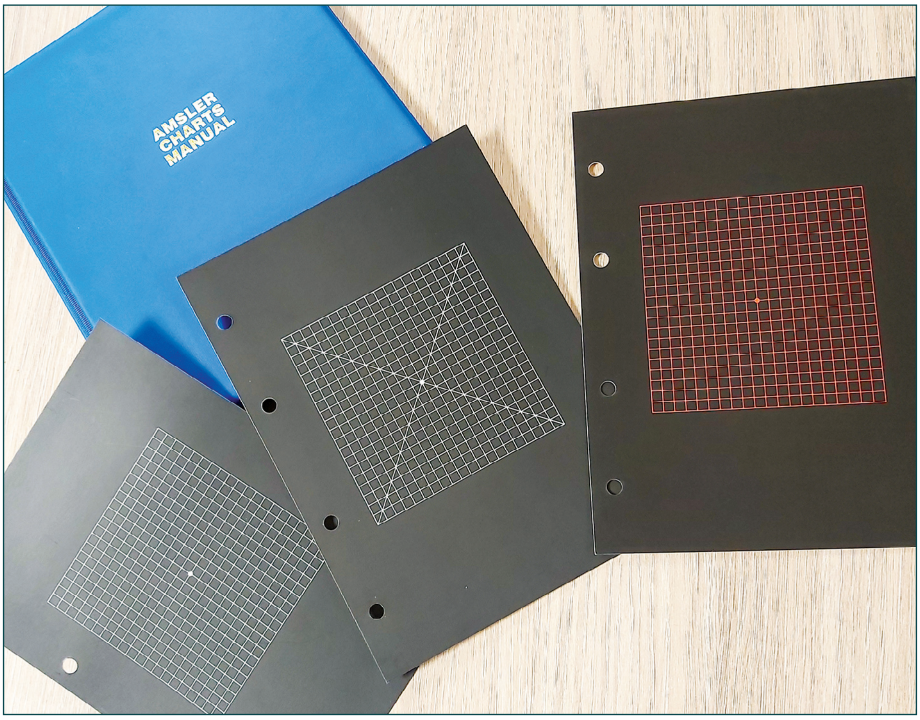

FIGURE 6: Amsler grids used for assessing macular fields

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References can be found when completing this CPD module. For a PDF of this article with references email, abdocpd@abdo.org.uk

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LEARNING OUTCOMES FOR THIS CPD ARTICLE

DOMAIN: Communication

2.1: *Communicate effectively eccentric viewing therapy to patients with pathologies affecting central macular vision in a way they can understand using professional judgement to adapt language and communication approach accordingly.*

DOMAIN: Clinical practice

5.3: *Recognise the importance of perimetry tests as a screening method for detection and monitoring of pathologies that disrupt visual function, taking into account current good practice and the latest research evidence to inform the care you provide.*

7.2: *Recognise the impact of peripheral visual field loss on the incidence of falls, and provide advice, investigations or treatment if required for your patient in a timescale that does not compromise patient safety and care.*

COMMUNICATION

CLINICAL PRACTICE

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