LEARNING DOMAINS

CLINICAL PRACTICE

PROFESSIONAL GROUPS

Dispensing opticians CPD PROVIDER General Optical Council

Optometrists CPD PROVIDER General Optical Council

CLOSING DATE: 7 August 2023

ANSWERS PUBLISHED: September 2023

CPD CODE: C-105280

MCQs AVAILABLE ONLINE: 1 May 2023

This CPD session is open to all FBDO members and associate member optometrists. Successful completion of this CPD session will provide you with a certificate of completion of one non-interactive CPD point. The multiple-choice questions (MCQs) are available online only from Monday 1 May 2023. Visit www.abdo.org.uk. After member login, scroll down and you will find CPD Online within your personalised dashboard. Six questions will be presented in a random order. Please ensure that your email address and GOC number are up-to-date. The pass mark is 60 per cent.

CPD CODE: C-105280

Vision beyond the eye

By Mark Hickton BSc (Hons), Cert Ed, FBDO, FHEA

As we move around our environment, our eyes take in light from the stimuli in our surroundings. Across our field of vision, the world looks sharp and colourful, and it is easy to think that our eyes are just like cameras, which send live images straight to our cognitive minds. Whilst our eyes optically image the world onto the retina, the resulting transmuted electrical nerve signals are just one part of a more complex holistic system, which creates our internal model of perception.

In our vocation, there is a natural focus on the health and function of the eye when examining vision for a patient. However, this article will highlight some of the visual processing and pathologies that can affect vision *beyond* the eye, and briefly discuss some of the visual processing areas of the brain involved in the construction of our perceptual model of the world around us.

EARLY PROCESSING

Visual perception begins with light being focused onto our retina by the refractive surfaces of the eye, forming an image or *proximal stimulus*[1]. The retinal receptor cells transmute the incident light into electrochemical signals that, after some low-level processing, are transmitted by the nerve fibres of the optic nerve. The majority of these nerve fibres travel to the visual areas of the thalamus known as the lateral geniculate nuclei (LGN), via the optic chiasma (**Figure 1 - opposite**).

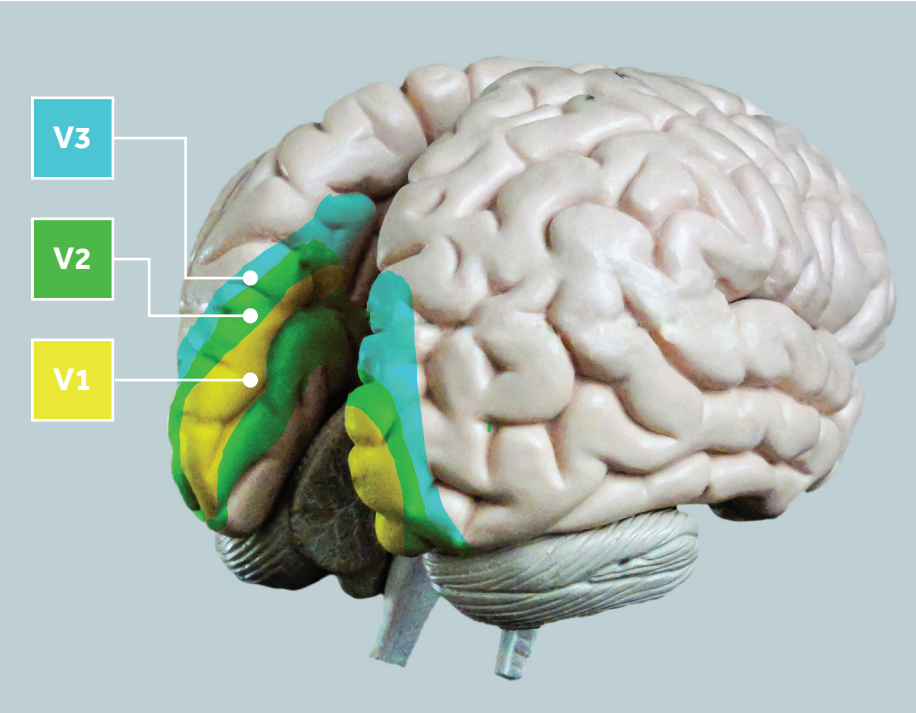

FIGURE 2: Some of the early visual processing areas of the brain (showing the occipital hemispheres slightly separated)

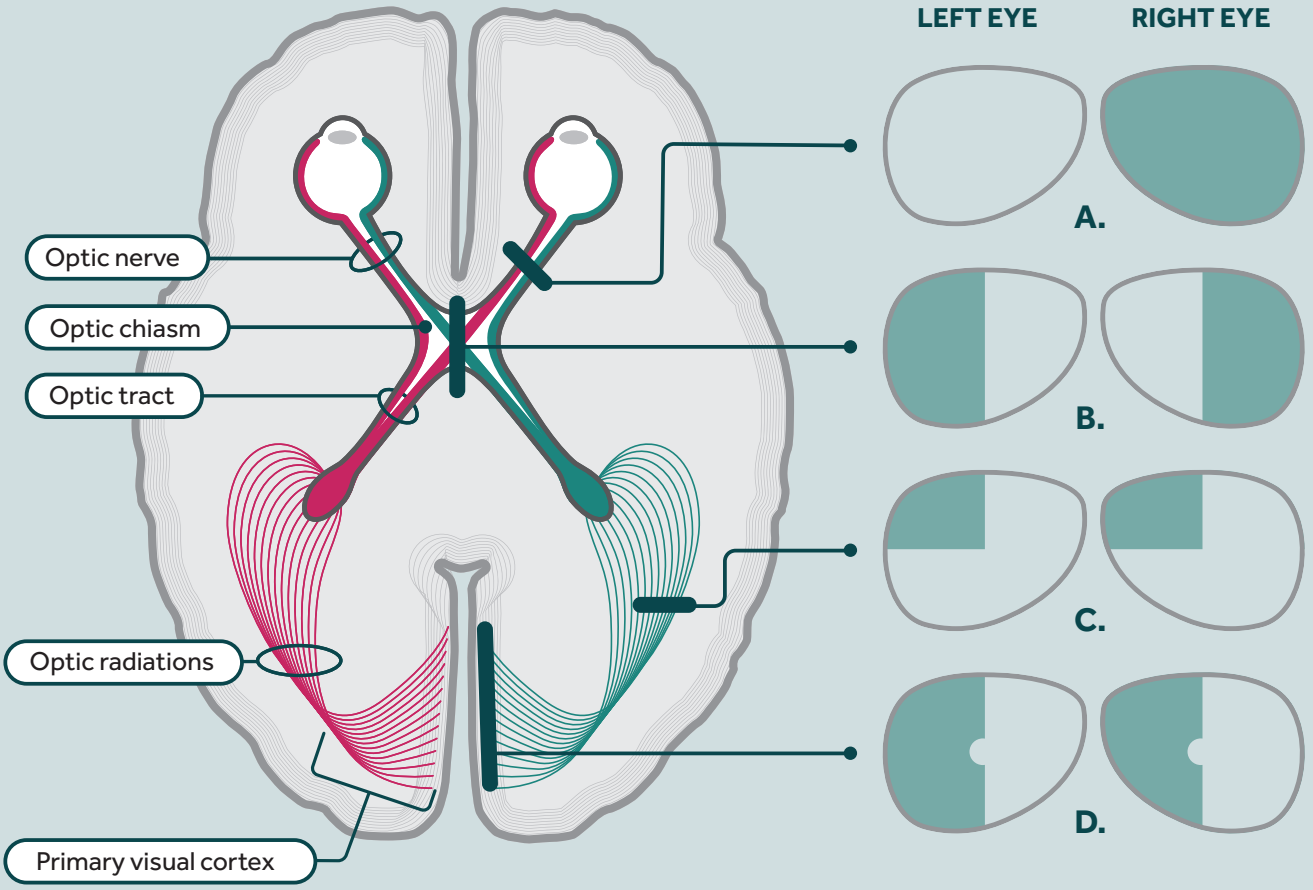

FIGURE 1: The early visual pathways to the primary visual cortex, showing examples of associated field loss with lesions affecting the indicated parts of the pathway. A: monocular RE blindness; B: bi-temporal heteronymous hemianopia; C: quadrantanopia; D: homonymous hemianopia with macula sparing[9]

Johns, P. (2014) *Clinical Neuroscience.* London: Elsevier Health Sciences

The thalamus is a sensory relay station of the brain, with areas dedicated to receiving and regulating afferent visual, auditory, and tactile sensory signals (bottom-up signals)[2,3]. It is important to note that the LGN, and other sensory nuclei of the thalamus, receive significantly more top-down neural information that has already been processed from the visual cortex and other areas of the brain[1,3-5].

This feedback loop hints at a visual system that reinforces perceptual behaviour and phenomenology by continuous feedback and experiential learning[6]. From the LGN, visual processing continues on via the optic radiations to the primary visual cortex (sometimes referred to as the striate cortex, or visual area V1), located in the occipital lobe of the brain.

Although the visual cortex is essential for primary construction of the visual percept, performing simple processes such as edge and orientation perception[4,7,8], full visual processing involves many other areas outside V1. These 'extrastriate' areas (V2, V3, V4, etc) typically radiate outwards from the primary visual cortex[4,9] and perform more complex signal processing, with increasing perceptual element specificity, based on the signals originating from V1; this is often referred to as higher-order visual processing (**Figure 2**).

PROCESSING STREAMS

It is generally agreed that there are two main visual processing streams that extend from the visual cortex: the dorsal and ventral streams (**Figure 3 - see next page**). The dorsal stream typically relays visual information that aids with spatial processing and motion perception, and links with our motor-system; as such, this stream is sometimes referred to as the 'where' stream[4,5,9,10-12]. This stream extends from the primary cortex to the motor-areas in the parietal lobes, and onwards to the frontal cortex[13].

Visual processing via this stream influences eye movements to attend stimuli, and, therefore, fast conduction velocities are required for our bodies to interact and react within our environment. Due to this demand, much of this dorsal visuomotor pathway consists of inputs from larger magnocellular neurons that can more rapidly conduct nerve signals[4,14,15].

Reaching and grasping, in which our reach and grip-span are adjusted sub-consciously when picking up objects, is an example of how our dorsal visual processing supports movement actions[10]. Additionally, it is believed that most of the dorsal visual processing results in *unconscious* perception that informs our actions, but is not made aware to us consciously[10,13,16].

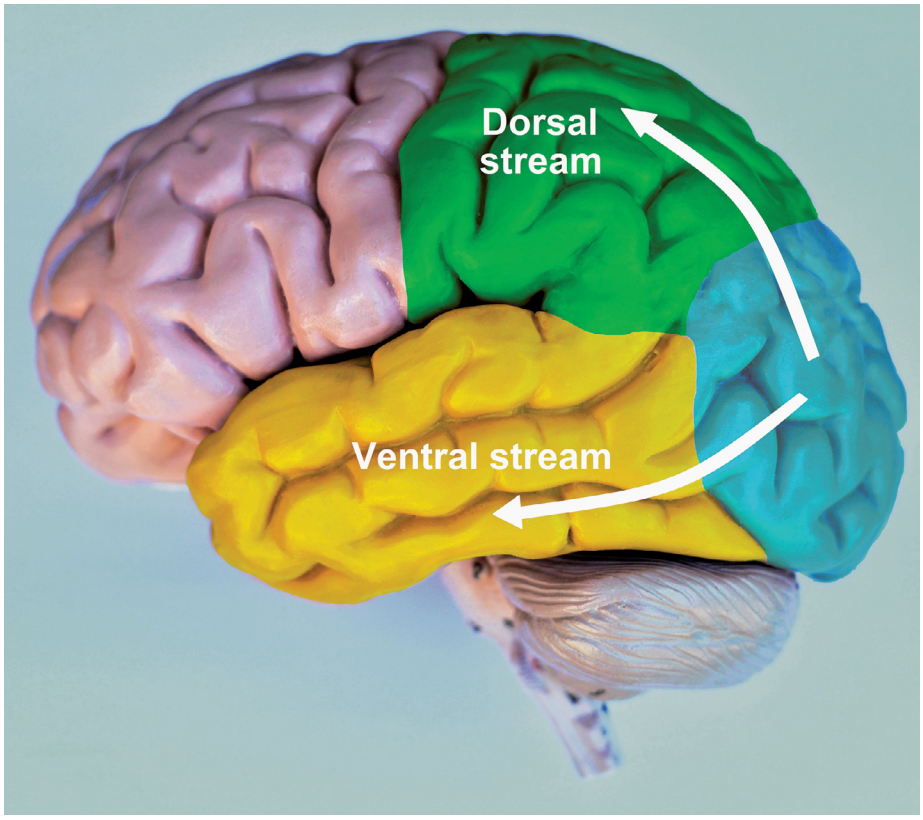

FIGURE 3: The dorsal processing stream radiating from the occipital lobe (blue) to the parietal lobe (green) and beyond. The ventral stream radiates from the occipital lobe and onto the temporal lobe (yellow)

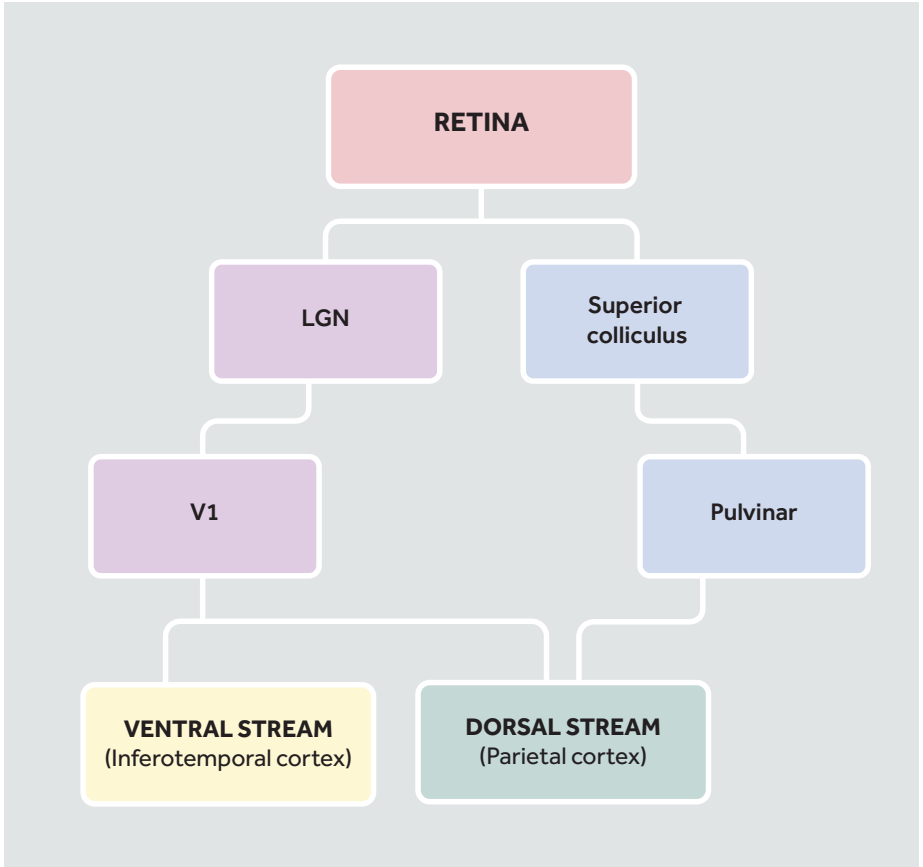

FIGURE 4: Visual information processed via the superior colliculus pathway can reach the dorsal stream for unconscious processing[7,10]

The ventral stream, extending from the visual cortex to the temporal lobes, processes visual information for the purposes of conscious perception and cognitive object recognition, and is therefore referred to by some as the 'what' stream[4-5,9-12]. Smaller, slower conducting, parvocellular neurons are commonly connected with the ventral stream, and are suggested to help convey signals relating to perceptual elements, such as colour and form[5,7].

Although these two processing streams have distinct functions, it has been found that there are still many connections between the two streams to allow cross-modal integration in the processing of vision[12]. Additionally, all sensory processing areas are interlinked[1,2], interacting with other visual and non-visual sensory input information to create our perceptual model. Although how this vast network of information processing forms our visual consciousness is still unclear[7], our experience of the world around us emerges from this complex holistic processing and interconnectedness of sensory and experiential data.

OCULOMOTOR CONTROL NUCLEI

Whilst the majority of the visual processing streams radiate from the LGN to the primary visual cortex, approximately 10 per cent of the optic nerve fibres take visual sensory information to oculomotor control areas and midbrain structures, such as the superior colliculus and pulvinar[1,5,10], which help mediate oculomotor functions such as eye-movements, saccades, and attention to visual stimuli[4,7,11,17,18].

Further nerve pathways extend to areas that influence pupillary control, such as the Edinger-Westphal nucleus in the brainstem[4]. Additionally, visual information that has been processed in the visual cortex also returns to the superior colliculus via the dorsal stream[12], allowing salient visual information to guide our oculomotor systems in directing attention to important objects in the scene.

NEURAL VISUAL DEFECTS

Pathologies affecting any part of the visual processing structures beyond the eye itself can produce a wide variety of

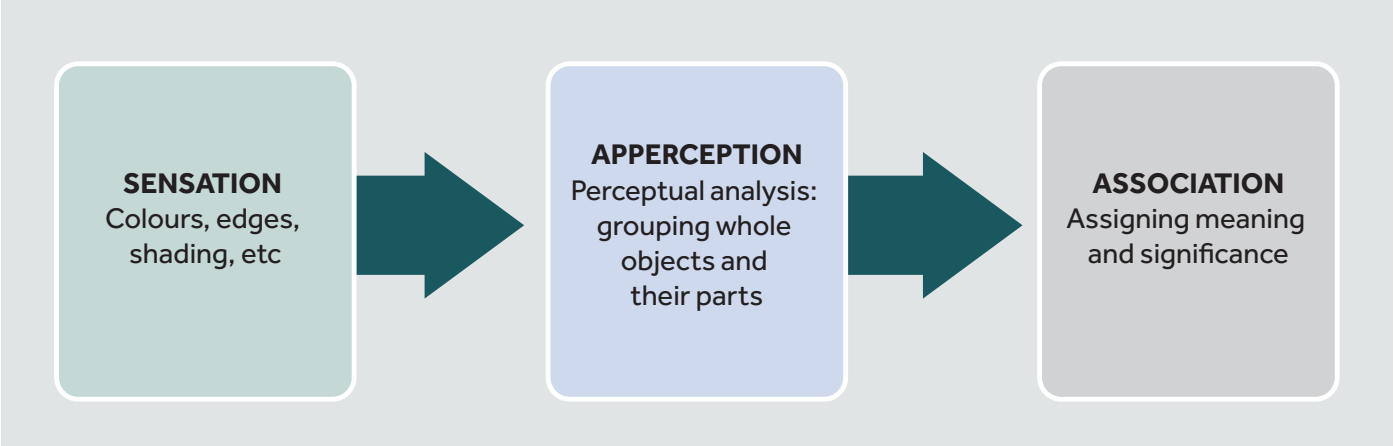

FIGURE 5: A simplistic grouping process for the different types of agnosia[10]. Neural damage disrupting the first link will result in apperceptive agnosia, whereas damage in areas of the brain relating to the second link will result in associative agnosia

symptoms, depending on the neural areas involved. Neurodegenerative disease (NDD), ischaemia, and traumatic brain injury (TBI) are some causes that can result in neural cell deterioration and death, thus disrupting the processing of visual signals within the affected areas of the brain[9,17,19].

Any disruption in the early processing visual pathways, between the eye and V1, can result in scotomas of the visual field (**Figure 1**). As such, visual field monitoring should be embedded into any eye examination in which the patient declares a potential neurological condition, such as a stroke.

Pathologies or trauma affecting the primary visual cortex (V1) invariably have considerable impact on visual processing. As the majority of extrastriate visual processing, in which more complex features of the percept are formed, radiates from the initial processing in the primary cortex, lesions within the primary cortex generally result in severe field scotomas to complete loss of cognitive vision[19-21].

When 'cognitive' vision is lost in such cases, studies have shown that some visual processing may occur at unconscious levels (known as 'blindsight')[4,10,20,22]; for example, in cases of preserved dorsal stream function, cognitively-blind patients may still be able to process object spatial position, orientation, and motion to allow unconscious interaction within their environment. Although damage to V1 or other extrastriate areas will severely disrupt conscious visual processing, the dorsal stream can access and process some visual information via the superior colliculus pathway[7,8,21] (**Figure 4**).

Visual neural areas beyond the primary visual cortex can produce a variety of symptoms if damaged and, whilst they may not be as debilitating as complete vision loss, they nonetheless can result in life-changing visual deficits and cognitive issues. The full process of conscious visual perception allows us to view complex scenes, differentiate and group stimuli within those scenes, and assign meaning and recognition to the viewed objects. A group of rare perceptual disorders that can affect the interlinking of vision and recognition are described by the general term of agnosia[23,24] (from the Greek *a-*: without; *-gnosis*: knowledge)[9].

Agnosia related to ventral stream damage, particularly in the occipital-temporal regions and temporal lobe, tend to result in conscious visual impairment and recognition. In some forms of visual agnosia, the perceptual process is disrupted at an early stage (but beyond basic retinal and low-level processing) and subjects will report an impairment in their ability to visually perceive objects; this is described as apperceptive agnosia or visual form agnosia[9,22,23]. Patients may be able to perceive some perceptual elements (i.e. colour), but not be able to recognise object shapes or structures.

Some forms of visual agnosia present with subjects that cannot cognitively recognise the object at hand, or remember associated knowledge relating to the function of the object, despite possessing a good level of visual acuity; this is known as associative visual agnosia (though recognition of the object through other sensory modalities is still possible)[9,10,22,23].

For example, subjects with associative agnosia will be able to perceive and describe the shape and visual features of an object, say an apple, but will not be able to identify it as an apple by sight alone. Curiously, however, when asked to draw an apple from memory, the drawing will be reasonably accurate but the subject will not be able to recognise their own drawing as an apple when presented later. **Figure 5** shows a simple grouping process for the different types of agnosia.

Patients with extensive lesions of the ventral pathway will generally have poorer levels of perception, with impaired ability to recognise shapes or to group elements of the scene perceptually, but can retain some unconscious visuomotor processing through the intact dorsal stream[10].

Goodale and Milner[10] highlight a case of visual apperceptive agnosia in which the patient presented with poor levels of vision, only perceiving shades of colour and vague shapes, after damage to the middle-temporal (MT) area. It was found, however, that unconscious visual processing was still occurring, as the patient was shown to reach out and grasp objects, and orientate their hands in the necessary direction. This included rotating their hand to the correct orientation to 'post a letter' through a variably orientated slot, but not being able to consciously describe the visual orientation of the slot.

As discussed earlier, dorsal stream processing generally informs unconscious visuo-motor and visuospatial processing, and thus damage to areas of the dorsal stream,

in either the occipital or parietal lobes, can often manifest with symptoms that affect motor co-ordination and planning. Optic ataxia and apraxia are two conditions which can arise through dorsal-stream damage in the parietal lobe[9,25].

Optic ataxia is associated with poor visually-guided motor actions, such as reaching or pointing; whilst subjects can clearly see objects, they cannot easily guide their hand or avoid other obstacles, when reaching for such objects[10,25]. Whilst similar, optic apraxia affects the planning and execution of actions supported by visual processing, such as manipulation of objects or the miming of actions[9,26,27].

Simultanagnosia is a form of agnosia typically associated with dorsal stream lesions (though simultanagnosia associated with the ventral stream has also been recorded). Patients with this condition have difficulty perceiving and recognising multiple elements of a visual scene at the same time[23,28], and is generally thought to be due to poor attentional scope, and a loss of visual information to guide eye movements and saccades.

Despite possessing a full-field of vision, simultanagnosia restricts the ability to perceive whole scenes at once; this can make sufferers appear to be blind in their movement around visually complex environments[23]. With more extensive bi-lateral lesions of the parietal lobes, simultanagnosia, optic ataxia and optic apraxia, may all be present in a patient's neuropathology, with this triad of deficiencies referred to as Balint's Syndrome[10,17,19].

Visual processing typically becomes more specialised and selective as processing continues outwards from the primary cortex and along the visual streams, and more specialised neurons are observed which only respond to very specific visual stimuli, such as faces, places, and words, etc. Damage to these very specialised areas can result in more selective forms of agnosia; for example, damage to the fusiform gyrus in the inferior occipital-temporal region can result in prosopagnosia, a condition in which the ability to visually recognise faces (even your own) is lost despite normal levels of acuity[9,23,29].

The precessing discussions represent a handful of the possible agnosias and syndromes that can affect perceptual behaviour with damage to the processing streams; lesions within various visual processing areas can result in a wide range of symptoms, and **Table 1** briefly highlights some other abnormalities affecting higher-order perception.

Higher-order visual deficits, such as the ones discussed, can also present as early signs of neurodegenerative disease. Posterior cortical atrophy (PCA) syndrome is generally considered as an atypical form of Alzheimer disease that initially affects the occipital and parietal lobes, though other pathological causes can be associated with the onset of this syndrome[26,31,32]. Unlike typical Alzheimer symptoms, which include patients presenting with impaired cognition and episodic memory, initial symptoms of PCA can present as visual perceptual impairment and agnosia[19,31]. As PCA progresses to later stages, more symptoms typically associated with Alzheimer disease will begin to manifest, affecting cognitive and memory functions.

Visual pathologies affecting the higher-order processes of perception can be difficult and time-consuming in their recognition and diagnosis, and it is suggested that many presenting with neurodegenerative disease, such as PCA, or traumatic brain injury (TBI) may not be diagnosed easily, or even misdiagnosed, at an early stage[19,31,33]. Factors that can hinder diagnosis may be the absence of cognitive symptoms in the early stages of some of the NDD discussed, leading to practitioners focusing on eye-related causes, and the rarity of such disorders which relate to lack of training and testing[33].

VISUAL PROCESSING DISORDER	DESCRIPTION
Pure alexia	A selective agnosia, often linked with ventral-stream simultanagnosia, in which a subject has good acuity but cannot see words as a whole and thus resulting in severe reading difficulties[23].
Optic aphasia	Sometimes referred to as a mild version of associative visual agnosia, whereby an inability to recognise an object is present (despite good visual acuity) but, unlike associative agnosia, some knowledge associated with the object is retained (i.e. function)[23,25].
Topographic agnosia	Topographic agnosia is the inability to recognise familiar places or landmarks, despite normal acuity[23].
Akinetopsia	A very rare inability to perceive motion[10,30]; subjects report visual experiences as being frozen and, without seeing motion, moving objects in scenes appear as a series of stationary snapshots[1,10].
Cerebral achromatopsia	The inability to perceive colour, despite healthy cone photoreceptors; commonly associated with damage to the V4 and V8 areas of the brain[5,7,10,25].
Spatial neglect	The lack of awareness (sometimes multi-sensory) of one side of the cognitive space, typically on the contralesional side, traditionally associated by lesions of the lower parietal lobe[10,26].

TABLE 1: Some other examples of forms of visual agnosia and perceptual disorders[4,10,23,24]

CEREBRAL VISUAL IMPAIRMENT

Any of the aforementioned pathologies can result in a dysfunction in visual processing known as cerebral visual impairment (CVI). Although this term does not readily suggest a link with the age of the subject, CVI has more recently been discussed within a paediatric context. Within this context, CVI has been defined as 'a verifiable visual dysfunction which cannot be attributed to disorders of the anterior visual pathways or any potential co-occurring ocular impairment'[34].

CVI is quite a generalised term anatomically, as the cortex and processing areas of the brain cover a large area and a number of specialised processing regions. Hence, CVI could present with very diverse signs and symptoms based on the area affected. Recent studies in paediatric CVI have highlighted a potentially hidden health concern within the populace[13,35-38], with birth complications, premature birth, and atypical early development suggested to be a potential aetiology for paediatric visual processing deficits.

DEVELOPMENTAL DYSLEXIA

Dorsal stream processing and, in particular, magnocellular cell deficits, have been also been implicated as a factor in the cause of developmental dyslexia[7,14,39]. As the magnocellular neurons within the dorsal stream conduct large amounts of visual information very rapidly, it has been suggested that a deficit in this stream will impact on sequencing and temporal processing of visual information, leading to poorer visual recognition of letters and a reduced ability to attend individual letters and words.

The pathophysiology of developmental dyslexia is both complex and multifactorial; alongside magnocellular dysfunction, other visual processing and phonological deficits have been proposed as underlying influences[15,39].

HOLISTIC VISUAL PROCESSING

Eagleman[40] highlights the holistic nature of our visual processing systems by discussing a surgical case in which it was hoped that sight would be restored to a patient known as MM.

MM had been blinded from the age of three in a chemical explosion. After 40 years of blindness, pioneering stem-cell surgery was delivered to repair the damage to the patient's corneas. Although the operation was a 'success', in the sense the eye-system could form clear retinal images allowing the patient to see light and colour, the patient could not perceive the world or make sense of the incoming visual information. Even though many years have passed since the surgery, MM can see light, colours and shapes, but still has extreme difficulty assigning depth and meaning to the visual information, almost like a form of apperceptive agnosia.

This case shows how our perceptual model of the world is based on modular processing by many neural areas, and develops from birth with visual information combining with motor inputs and other sensory information. Many of these pathways form at very early stages in life[37], and thus highlights the importance of establishing good visual input and correction to avoid disruption at the very beginning of the perceptual process.

SUMMARY

The human brain is the most complex machine found in nature and, with more than 50 per cent of the brain being involved in visual processing[7], consideration of the entire visual system is vital in the understanding of perception. With the mounting evidence of the impact of neurological disorders and trauma in visual processing, it is necessary in our field of work to consider the patient's visual needs holistically, and to have awareness of potential symptoms that may be indicative of visual processing deficits.

As the eye is essentially a sensory extension of the brain, there are studies that suggest optical coherence tomography (OCT) scans of the eye could potentially be used in the future to detect changes related to NDDs[41,42]. Early diagnosis of these deficits can help initiate support processes, such as NDD treatment plans and, especially in the context of paediatric CVI, additional learning support within education[13,35].

REFERENCES

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

MARK HICKTON has been a lecturer in ophthalmic dispensing at Bradford College for more than 14 years, and is a practising dispensing optician with over 24 years of experience within the optical industry. Mark is the module leader for the Optics and Ophthalmic Lenses modules, and his college scholarly activity revolves around the area of visual and audio-visual perception. Mark is a Fellow of the Association of British Dispensing Opticians, and a Fellow of the Higher Education Academy. Mark is an experienced CPD author.

LEARNING OUTCOMES FOR THIS CPD ARTICLE

DOMAIN: Clinical Practice

5.3: *Be aware of the current understanding around vision processing in the brain, how this may impact a patient's visual perception depending on any pathologies that may be present, and consider how this information may impact your clinical practice.*

7.1: *Conduct an adequate assessment for the purposes of the optical consultation, including where necessary any relevant medical history that may assist in a better understanding of the patient's visual perception.*

CLINICAL PRACTICE

References

1. Goldstein EB and Brockmole JR. *Sensation and Perception*. 10th ed. Boston: Cengage Learning, 2016.
2. Froesel M, Cappe C and Hamed SB. A multisensory perspective onto primate pulvinar functions. *Neuroscience & Biobehavioral* Reviews 2021;125;231-243.
3. Weyand TG. The multifunctional lateral geniculate nucleus. *Reviews in the Neurosciences* 2016;27(2):135-157.
4. Carpenter R and Reddi B. *Neurophysiology – A conceptual approach*. 5th ed. London: CRC Press, 2012.
5. Stone JV. *Vision and Brain – How we perceive the world*. Cambridge: Massachusetts Institute of Technology, 2012.
6. Gilbert CD and Li W. Top-down influences on visual processing. *Nature Reviews Neuroscience* 2013;14:350-362.
7. Snowden R, Thompson P and Troscianko T. *Basic Vision – an introduction to visual perception.* Revised ed. Oxford: Oxford University Press, 2012.
8. Bruce V, Green PR and Georgeson MA. *Visual Perception: Physiology, Psychology, and Ecology*. 4th ed. Hove: Psychology Press, 2003.
9. Johns P. *Clinical Neuroscience*. London: Elsevier Health Sciences, 2014.
10. Goodale M and Milner D. *Sight unseen: An exploration of conscious and unconscious vision.* Oxford: Oxford University Press, 2013.
11. Carter R. *The human brain book: An illustrated guide to its structure, function, and disorders.* 3rd ed. London: Penguin, 2019.
12. Milner AD. How do the two visual streams interact with each other?. *Experimental brain research* 2017;235(5):1297-1308.
13. Donaldson L. An introduction to paediatric cerebral visual impairment. *Optometry Today* 2019;59(6):62-66.
14. Stein J. What is developmental dyslexia? *Brain sciences* 2018;8(2):26.
15. Werth R. Is Developmental Dyslexia Due to a Visual and Not a Phonological Impairment?. *Brain Sciences* 2021;11(10):1313.
16. Sperandio I and Chouinard PA. The mechanisms of size constancy. *Multisensory research* 2015;28(3-4):253-83.
17. Armstrong RA. Visual problems associated with traumatic brain injury. *Clinical and Experimental Optometry* 2018;101(6):716-726.
18. King AJ. The superior colliculus. *Current Biology* 2004;14(9):R335-R338.
19. Pelak VS. The clinical approach to the identification of higher-order visual dysfunction in neurodegenerative disease. *Current Neurology and Neuroscience Reports* 2022:1-14.
20. Ajina S and Bridge H. Subcortical pathways to extrastriate visual cortex underlie residual vision following bilateral damage to V1. *Neuropsychologia* 2019;128:140-149.
21. Kaas JH and Baldwin MK. The evolution of the pulvinar complex in primates and its role in the dorsal and ventral streams of cortical processing. *Vision* 2019;4(1):3.
22. Eysenck MW and Brysbaert M. *Fundamentals of Cognition*. 3rd ed. Abingdon: Routledge, 2018.
23. Farah M. *Visual Agnosia*. 2nd ed. Cambridge: MIT, 2004.
24. Martinaud O. Visual agnosia and focal brain injury. *Revue Neurologique* 2017;173(7-8):451-460.
25. Turgut B, Karanfil FC and Turgut FA. Abnormalities in higher cortical visual processing. *Adv Ophthalmol Vis Syst* 2018;8(4):202-210.
26. Coslett HB. Apraxia, neglect, and agnosia. *Continuum: Lifelong Learning in Neurology* 2018;24(3):768-782.
27. Goldenberg G. Apraxia and the parietal lobes. *Neuropsychologia* 2009;47(6):1449-1459.
28. Mazza V. Simultanagnosia and object individuation. *Cognitive neuropsychology* 2017;34(7-8):430-439.
29. Albonico A and Barton J. Progress in perceptual research: The case of prosopagnosia. *F1000Research* 2019;8.
30. Ardila A. Some unusual neuropsychological syndromes: Somatoparaphrenia, akinetopsia, reduplicative paramnesia, autotopagnosia. *Archives of Clinical Neuropsychology* 2016;31(5):456-464.

31. Schott JM and Crutch SJ. Posterior cortical atrophy. *CONTINUUM: Lifelong Learning in Neurology* 2019;25(1):52-75.

32. Migliaccio R, Agosta F, Scola E, Magnani G, Cappa SF, Pagani E, Canu E, Comi G, Falini A, Gorno-Tempini ML and Bartolomeo P. Ventral and dorsal visual streams in posterior cortical atrophy: a DT MRI study. *Neurobiology of aging* 2012;33(11):2572-2584.

33. Vancleef K, Colwell MJ, Hewitt O and Demeyere N. Current practice and challenges in screening for visual perception deficits after stroke: a qualitative study. *Disability and Rehabilitation* 2020;44(10):2063-2072.

34. Sakki HE, Dale NJ, Sargent J, Perez-Roche T and Bowman R. Is there consensus in defining childhood cerebral visual impairment? A systematic review of terminology and definitions. *British Journal of Ophthalmology* 2018;102(4):424-432.

35. Pilling RF, Allen L, Bowman R, Ravenscroft J, Saunders KJ and Williams C. Clinical assessment, investigation, diagnosis and initial management of cerebral visual impairment: a consensus practice guide. *Eye* 2022:1-8.

36. Bennett CR, Bauer CM, Bailin ES and Merabet LB. Neuroplasticity in cerebral visual impairment (CVI): assessing functional vision and the neurophysiological correlates of dorsal stream dysfunction. *Neuroscience & Biobehavioral Reviews* 2020;108:171-181.

37. Leung MP, Thompson B, Black J, Dai S and Alsweiler JM. The effects of preterm birth on visual development. *Clinical and Experimental Optometry* 2018;101(1):4-12.

38. Kran BS, Lawrence L, Mayer DL and Heidary G. Cerebral/cortical visual impairment: a need to reassess current definitions of visual impairment and blindness. *Seminars in pediatric neurology* 2019;31:25-29.

39. Nicolson RI and Fawcett A. *Dyslexia, learning, and the brain*. Cambridge: MIT press, 2010.

40. Eagleman D. *The Brain: The story of you*. Edinburgh: Canongate Books, 2016.

41. Marchesi N, Fahmideh F, Boschi F, Pascale A and Barbieri A. Ocular Neurodegenerative Diseases: Interconnection between Retina and Cortical Areas. *Cells* 2021;10(9):2394.

42. Nguyen CT, Acosta ML, Di Angelantonio S and Salt TE. Seeing Beyond the Eye: The Brain Connection. *Frontiers in Neuroscience* 2021;15:796.