Course Introduction

Flatlanders – Vision Blindness

Adapted from the Wikipedia regarding the book "Flatland: A Romance of Many Dimensions", by Edwin Abbott, published 1884.

> *The story describes a two-dimensional world occupied by geometric figures, whereof women are simple line-segments, while men are polygons with various numbers of sides. The narrator is a square, a member of the caste of gentlemen and professionals, who guides the readers through some of the implications of life in two dimensions. The first half of the story goes through the practicalities of existing in a two-dimensional universe as well as a history leading up to the year 1999 on the eve of the 3rd Millennium. …*
>
> *In brief, Square is taken on a journey to Spaceland where his mind is blown when he realizes there are so many advantages in a 3D world.*
>
> *The Square recognises the ignorance of the monarchs of Pointland and Lineland and his own (and the Sphere's) previous ignorance of the existence of higher dimensions (i.e is there a 4^{th} dimension?). Once returned to Flatland, the Square cannot convince anyone of Spaceland's existence, especially after official decrees are announced that anyone preaching the existence of three dimensions will be imprisoned (or executed, depending on caste). Eventually the Square himself is imprisoned for just this reason, with only occasional contact with his brother who is imprisoned in the same facility. He does not manage to convince his brother, even after all they have both seen. Seven years after being imprisoned, A Square writes out the book Flatland in the form of a memoir, hoping to keep it as posterity for a future generation that can see beyond their two-dimensional existence.*

Children's learning readiness is most often poorly assessed in school – as a society, we spend much more attention and money ensuring our children are well-equipped for sports than we do on ensuring they have what they need for 12 years of schooling. Still, all children must attend school, while enrollment in sports is not compulsory. As a result, many avoidable problems are simply ignored and left to cause havoc over many years in school. In some cases, children and families will suffer miserably over years while professionals subject them to invasive testing and treatment that leads nowhere.

Something between 20% and 30% of children are ever assessed for visual functional problems and as a rule these assessments are incomplete. The number is much lower in the early grades and in marginalized or isolated communities. Still, depending on the population, anywhere from 20-40% of children in a given classroom will struggle against their vision. Teachers try to fill the children's learning 'buckets', but the buckets are riddled with holes. Vision is just not a concern because parents, teachers, doctors, and psychologists are never taught that it is, or could be a problem. To them, the world is still flat.

In the general population, the same concerns are there and are expressed in myriad ways. Whether an adult patient is in relatively good health, in declining health due to degenerative disease, or suffering from Traumatic Brain Injury, the role of vision remains critical, central in daily life, health, and recovery. As a doctor in clinic, my overall impression has been that most people have some degree of visual dysfunction that, when corrected or neutralized, leads to a noticeable if not life-changing benefit. Children are at a particular disadvantage in that they assume their normal is 'the' normal; given social, cognitive, and emotional constraints, most children are inclined to report no trouble with their vision, or to simply say 'yes' when asked if 'they can see that'.

After degrees in neural science and in education, I was still also a flatlander – while I was a good teacher, I had a blind spot when it came to vision. There's a lot more to the vision picture that we're just not taught in school – I needed to complete a doctorate in optometry to see the light at the end of the neurology and learning tunnel. The best news is that as a therapist, the power gained from expanding your own understanding of vision will immediately and significantly extend your reach and accelerate outcomes.

This course is largely about **sight** (but more broadly 'visual signal acquisition'), **glasses**, and how these affect **behaviour**, **learning**, and **rehabilitation**. For fun, let's call it 'physiological optics' – literally, how the brain uses the eyes to create clear, aligned imaging for downstream processing – and the challenges it faces in making this happen. Where there is a visual impediment due to trauma or development, visual signal acquisition will be affected and this in turn degrades downstream processing. If you consider all that is connected to vision, you'll start to get an idea of what this can mean: Cognition, Affect / Emotional Function, Fine Motor Control, Gross Motor Coordination, Locomotion, Balance, Orientation / Motor Reflex Responses, Obstacle / Threat Avoidance,

This episode on human vision, perhaps more than the others in this series, is an important step in advancing your own understanding of human vision and how it plays into the work you do, and at the same time how it affects your own life and behavior.

Preview

By the time you're done this course you'll be able to

- Differentiate between the essential refractive conditions: nearsightedness, farsightedness, astigmatism, anisometropia, aniseikonia, presbyopia.

- Categorize a refractive state as helpful or unhelpful. Distinguish between minimal refractive errors and those that are significant or severe.

- Analyze the specific nature of each of the refractive states and their impacts on performance.

- For individual clients and in general, assess and describe how refractive states impact on human development and learning outcomes.

- Apply your knowledge and understanding to identify from simply observing whether someone has nearsight (myopia), farsigh (hyperopia), or ‘old sight’ (presbyopia).

- Read and assess auto-refractor strips to arise at science-based conclusions about your client’s needs and behavior. Gain insight into those in your care, with an emphasis on child development and behaviour.

- Evaluate and assess one of the most commonly undiagnosed impediments to learning and development – Refractive State.

- Investigate lens properties and recognize where some optical solutions may be better in some cases than in others.

I hope you enjoy this program – it’s ideal for parents, teachers, family doctors, school staff, and psychologists. There’s much more to come, starting with a quick primer on human vision. Other courses in this series present much more detailed information that you should pursue, but for now we’ll undertake a simple quick review of things.

Introduction

Let there be light. When the lights go on, a miracle happens. No fewer than 8 of 12 cranial nerves are activated and coordinated in a process we call vision. These nerves and an army of muscles make it easy for us to locate, fixate, and study the thousands of things we study in our daily lives. They also make it possible for us to map our surroundings, do acrobatics, imagine things and events that don’t yet exist, and to read music.

Vision is a complex neurological experience the most complex sensory experience we can have or make use of. Arguably the most important element of vision is sight. Certainly, it’s the one most people think or talk about when discussing vision.

To the parent and clinician, the refractive state of a child is one of the most potent metrics to track. How a child sees, or struggles to see, is critical in determining health, development, and learning outcomes. A farsighted child is much more likely to struggle in school than is his nearsighted peer, for one simple example.

This short course is an introduction to refraction, that is, the measurement and description of how we focus light with our eyes to see the world clearly – and what happens when things go awry. We’ll give you enough to get you moving forward to investigate vision in more detail and show you how to get the answers you need. Clearly, if you’re not paying attention to vision and refraction, you are missing one of the most important pieces of the puzzle – something that often enough will answer all those niggling ‘why does this child do this?’ sorts of questions. Let me help you get started with what I hope is an engaging, worthwhile, and down to Earth short program.

Perfect vision is defined most commonly as a state where both eyes are aligned and focused clearly on the horizon with no effort whatsoever. This is called emmetropia, neutral sightedness, or a 'Plano' (zero) prescription. Vision as a sensori-neural and sensorimotor process has many component elements feeding into it and arising out from it.

Most people have some sort of deviation from emmetropia, and this is referred to as Refractive State, or erroneously the 'Refractive Error', or simply refraction – all nouns. The process of measuring this offset is also called refraction, so a verb.

The following definition is from one of my favourite books, the **Dictionary of Visual Science and Related Clinical Terms** by Hoffstetter, et al. through Butterworth Heineman. You can still find these online:

Refraction:

1) The altering of the pathway of light from its original direction as a result of passing obliquely from one medium to another of different index of refraction.

2) The refractive and muscular state of the eyes, or the act or process of determining and/or correcting it.

The first definition is from physical optics – and you can see how light bends by observing prisms, diamonds, cut glass and minerals, or simply watching how people's legs seem to bend when they stand in water. So, refraction is the bending of light. In humans, the ultimate goal is to have those light rays from the environment come to perfect focus on the retinal receptor cells lining the inside contours of the eyes. Fosr most people, this is near perfect, or 'close enough' for horseshoes and requires only minimal effort. For many others, about 1 in 3, enough effort is needed to see that it puts a significant drag on the system.

The second definition of refraction correctly refers to the refractive and muscular state of the eyes, so **physiologifal optics**, or how does the brain flex the eyes in order to bifoveate a target (place the target clearly on both foveae). Visual process is served by no fewer than 8 of the 12 cranial nerves. Four pairs of these dedicated to coordinated movement of eyes, and another two to focusing and pupil constriction, the remaining pairs for movement of lids, facial muscles, and neck/shoulders for voluntary and reflex orientation. Vision takes effort – and ounce for ounce, the visual process takes more neuromuscular effort and energy than any other system in the body. When it's off, it can consume us.

The point of all this is that our brains and bodies spend a lot of energy servicing vision – to locate and fixate targets of interest, and to keep these targets clearly focused on retinal receptors. Vision is complicated and multilayered - but in this course we'll focus our attention on refraction. Vision and sight are also so central to our human identity and existence, you'll notice puns will be unavoidable at times.

We'll review the following:

1. How people receive light naturally. i.e. what it is like to have nearsight, farsight, astigmatism, and other conditions that we'll review.

2. What our eyes do to try to accommodate for any lack of clarity.

3. How this affects us in daily life and in clinic.

4. What can and should be done about it, accounting for purpose and age.

We're also going to have a look at some auto-refractor strips - that is, the machine readings of refractive states of several real-life cases. We'll go through what the auto-refractors measure and the information they provide. These are relatively inexpensive tools that help disclose critical information about the person you're talking about. And we'll throw in a comprehensive lens lab so you can learn to detect refractive states without ever talking to the client.

A Vision Primer

Introduction

Vision is the ability to use our eyes to understand the physical world without touching it, and to use visual information for thinking and for calculating muscle movements.

Vision relies upon one's understanding of where the body is in space, how it is positioned, and where other objects are in relation to the viewer. Only once this is understood can we even begin to direct our eyes towards objects of interest. In human neurology, this all requires the integration of some 65% of the brain's functions. A great part of the purpose of our brainstem functions, it seems, is to simply direct the head and eyes so we can 'read' the environment by using the shorthand of vision. That is, we use mature and highly efficient vision instead of touching and tasting the world like we once did as infants.

Most of us are familiar with the idea of an eye chart and how this can be used as a test of eyesight. This simple measure, visual acuity, provides useful information but is very limited in what it does tell us. Sight tests in schools, that is, distance visual acuity tests, ironically more often than not fail those children who are at a relative advantage in the classroom (nearsighted children), while passing most children who have significant visual impediments to learning (farsighted, astigmatism, vergence and accommodative disorders).

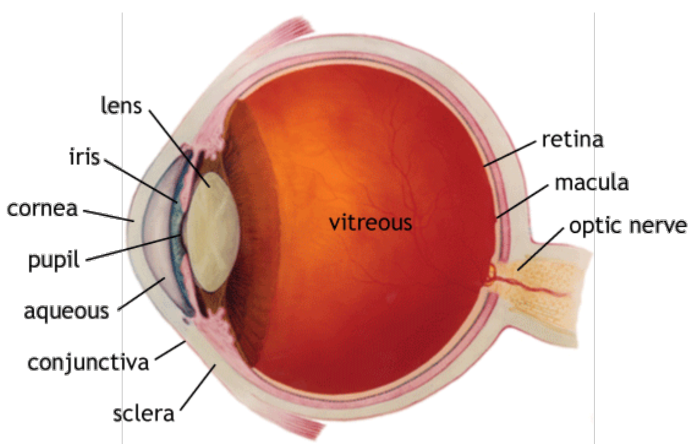
For developmental professionals, proper visual functional assessment and management is critical to diagnosing underlying conditions because many behavioural concerns are rooted in visual impediments. Because of this, many common diagnoses are in effect mis-diagnoses or missed diagnoses. Furthermore, addressing visual dysfunction opens the door to accelerated progress in collateral therapies by providing a stronger foundation for physical control, perception, and cognition. This and the following two chapters provide a practical overview of the varied aspects of the visual system and function that can and will negatively impact upon behaviour when affected by developmental problems or pathology.

Basic Visual Anatomy

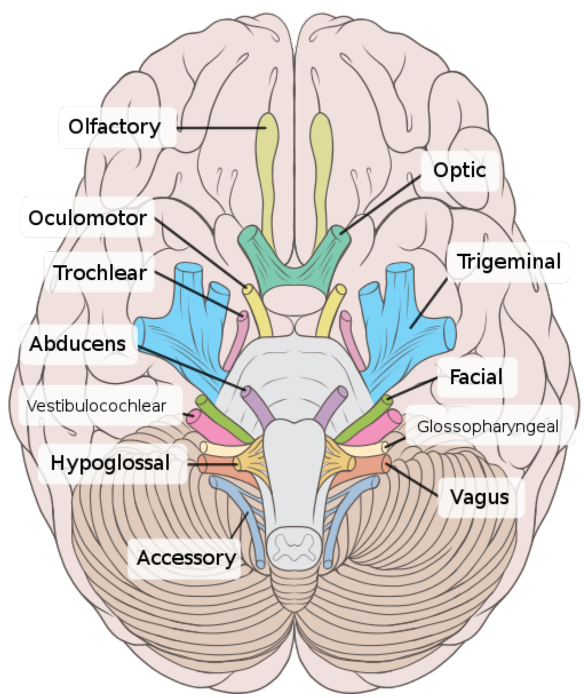
Vision is complex and integrated into some 65% of what our brains do. The eyes themselves are only one part of the visual process and are, obviously, the main tools used by vision to obtain sight-based information from the environment. Still, even if the eyes are closed, much of what the visual system does is still active; even if an individual becomes blinded, vision remains intact to a great degree because of its wide influence in the brain.

The visual system consists of internal structures, those we cannot see because they are inside the brain, and the external structures, namely the eyes. While the internal functioning of the visual system is important, we can really only infer what is happening by observing other behaviours, such as how a child responds to a test of visual memory, sequencing, or figure-ground, or by functional MRI, or by close study under a microscope. What is much simpler, more direct, and still very useful, is to study the details of the eyes' themselves and how they move. What the eyes do is a direct function of what the brain is telling them to do, and likewise, the limits of the what the eyes are capable of doing will determine to a great degree what the brain will perceive. This discussion, then, will focus on the elements of the eyes and those muscles that help to move them and to focus images.

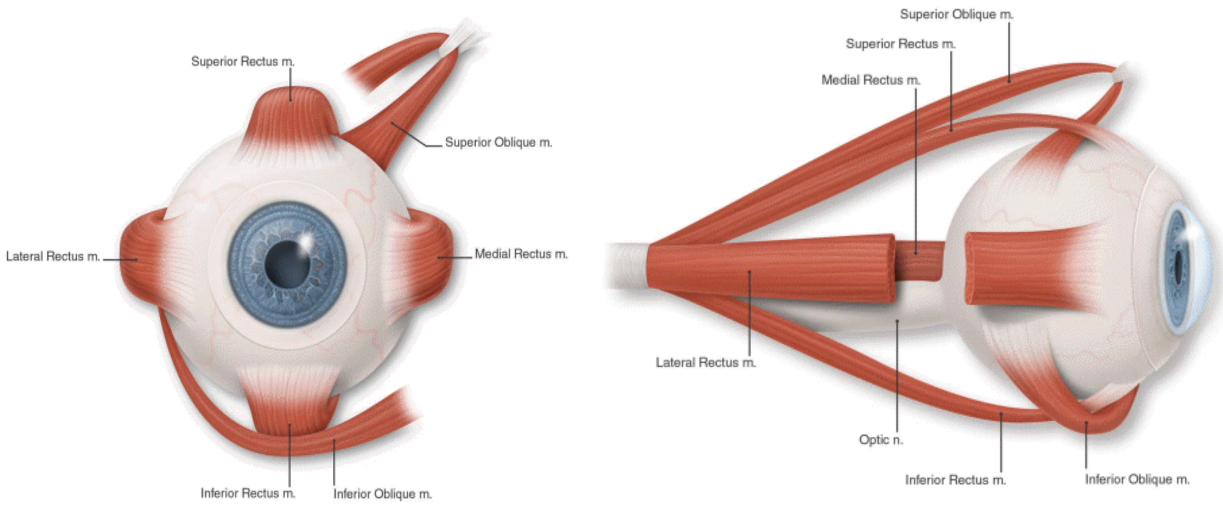
The eyes themselves are incredibly complex and a full description of their physiology and function is best left to books such as "Adler's Physiology of the Eye" by Kaufman and Alm (Mosby, 2002), or "Clinical Anatomy and Physiology of the Visual System, 3rd Ed.", by Remington (Elsevier, 2012).



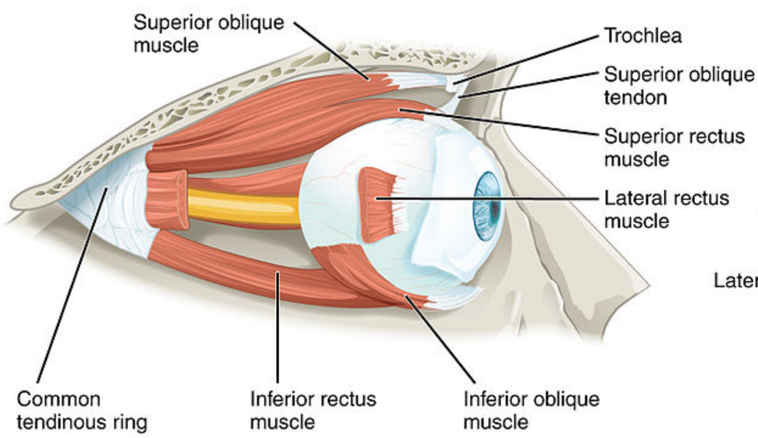
Schematic cross section of the human eye.



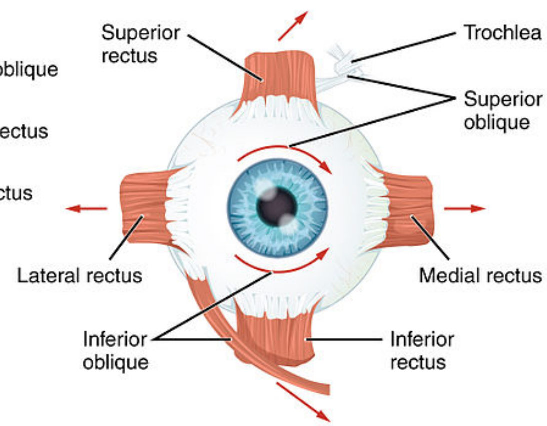
The 12 Cranial Nerves as viewed on the inferior, or under, side of the brain.



Extraocular muscles receive input from the brain to change the direction of the eyes and control fine eye movements.



Lateral view of the right eye



Anterior view of the right eye

For now, a brief overview of some of the elements of the eye structure is worthwhile:

- Each eye's movement is controlled by 6 muscles, the extraocular muscles.
- The eyes work independently of one another, but their movement is coordinated by different parts of the brain from brainstem to cortical areas.
- There are gross eye movements to quickly shift gaze or maintain gaze, and fine motor movements for very precise tracking of targets or moving quickly across text. Different movement types are controlled by different parts of the brain.
- Inside the eye, there are the *intraocular* muscles, those muscles primarily concerned with controlling the size of the pupil, and another set that controls focus.
- Each eye has an optic nerve that carries information to varied points in the brain, not just to the primary visual cortex.
- The retina, or the collection of light sensitive nerve fibers lining the inside of the eyes, is comprised of multiple layers of specialized cells.
- Of the 12 cranial nerves (CN), 8 are somehow related to visual function, helping to integrate touch, sound, sight, balance, and muscle control. The optic nerve (CN II) is one of these, the others include: oculomotor (CN III), trochlear (CN IV), trigeminal (CN V), abducens (CN VI), facial (CN VII), vestibulocochlear aka auditory-vestibular (CN VIII), and the accessory nerve (CN XI).

Optic Nerve: Also called Cranial Nerve II (CN II). It's interesting to note that when we look into the eye to observe the retina and optic nerve, we are actually observing live brain tissue in action!

Beyond the structure and function of the eyes themselves, there are numerous areas in most parts of the brain that are related to visual function and visual information processing. With 8 of 12 cranial nerves involved and dozens of interconnections inside the brain, it is easy to see that vision is very tightly integrated with many critical body and brain processes. In a similar fashion, because the visual system is so tightly integrated to brainstem functions, for example, even mild trauma, such as whiplash or other mild traumatic brain injury (mTBI) can and will have important effects on visual function. (See Notes section on 'cranial nerves' for more information.)

Elements of Vision

The eyes are the doorway to vision, but just like in any other case, the doorway is only the start, the opening. Even without a door, the house still stands, and all the rooms are there. The eyes are related to vision in this way – they are only one part of the whole system, and while vision requires sight to develop, once developed, many aspects of vision are still present even if the eyes are closed, or damaged. Vision can also be compared to a news photographer with a camera in-hand. The camera (the eyes, to be sure) have mechanisms to focus light and capture the focused light information. What the camera cannot do is point itself to objects of interest, or determine what those objects might be, or choose which objects to pay attention to. The camera also has limited computer processing power for anything but making the image appear, vision on the other hand can take the 'image' of what is seen and put it to good use in our minds, whether that means recognizing faces, or symbols on a page, or calculating that next stride for a hockey player in full flight.

Vision can be divided into three general categories of behaviours:

1. Skills that are required to target a visual signal of interest (that is, something we want to see). These are referred to as **Visual Signal Acquisition** (**VSA**) skills and consist of the mechanical side of vision.

2. Skills that are required for making sense of what it seen. These are mental behaviours best described as the computer software side to vision, and categorized as **Visual Signal Processing** (**VSP**)

3. Advanced behaviours that rely in large part upon visual input, such as cognition, balance, visual motor coordination, reading, gauging emotional responses, and others.

Let's have a quick look at VSA and VSP.

Visual Signal Acquisition – Finding What Is Important

Visual Signal Acquisition (VSA) is the mechanical side to vision, much like the camera in the hands of the photographer. The photographer will hold the camera just so, point it at the object of interest, compose and frame the view (that is, start to emphasize what is truly important in a scene), adjust the focal length of the lens and the amount of light required for good exposure, focus, and finally capture the image by releasing the shutter with a *click*!

The eyes function is a somewhat similar fashion in that they must be guided to the target of interest in a coordinated fashion (like having to handle two cameras simultaneously), the alignment of the cameras (eyes) must occur, then cropping and focusing. This requires action of the muscles on the outside of the eyes (the extraocular muscles) to point the eyes, but also of very small muscles in the eyes to focus the light. While we cannot control the focal length of the eyes, we can still adjust our attention so that we take in one specific element ('zoom in') or consider the entire scene as a whole ('zoom out').

The entire process of signal acquisition begins with a directive from the brain to capture some specific information. VSA, then, is that directive put into action by the visual system through control of eyes to target a visual signal, and make it as clear as possible to both eyes. Perhaps vision could be more accurately described as a video camera in that information is acquired as a continuous stream, but the still image of a photograph is also appropriate in that it emphasizes the fact that our vision is typically directed to highly some particular aspect of the scene.

Elements of Visual Signal Acquisition include:

1. **Pursuits** – smooth eye movements needed for tracking moving targets or balancing spatial awareness when the body moves or when objects move around the body.

2. **Saccades** – (suh-'kawds or suh-'kādes). 'Jump' eye movements. These can range from single long jumps, like from one scene to another on the complete opposite side of the visual field, to the rapid and automated very fine movements of fractions of millimeters such as are required for reading.

3. **Vergence** – The movement in opposing directions of the eyes such as occurs when looking near to far and back again – the eyes will go from a crossed position to a parallel position (divergence), then re-cross in order to see the near object (convergence).

4. **Versions** – These are movements of the eyes in the same direction, such as when then look up, down, left, right.

5. **Fixation** – The ability to maintain visual focus on a single object, keeping the eyes steady and on target.

6. **Posture** –When an eye is covered, it will move to its resting position, this is its posture. Given a target, most people's eyes will tend to want to naturally drift outwardly from a target (exophoria), or inwardly (esophoria).

7. **Alignment** – The eyes should be relatively balanced and symmetrical in their positioning. In the case of strabismus, one eye is misaligned when the other is on target.

8. **Focus / Accommodation** – The eyes will always try to maintain maximum clarity of an image.

9. **Central vs Peripheral Awareness** – These are the result of both internal brain functions, such as our internal mapping of external space, and the input of light from two parallel pathways that start in the retina: Central vision, involving the macula (the physical centre of the sensory tissue at the back of the eye where we perceive the greatest detail), and peripheral retina which comprises most of the light sensitive tissue by area and produces very poor visual acuity. Our attention switches from central to peripheral awareness both automatically, and when we tell it to.

10. **Eyesight / Refractive State** – the refractive, or resolving power of the eye to focus images. This is a matter of 'bending' and 'straightening' light so it can be focused onto the retina. The focusing system contributes only part of the focusing ability of the eye, the rest is static; it is the static part of the focusing power that is the source of most focusing problems. There are a great variety of refractive combinations that exist, and each has its own effect on vision and behaviour; for example, nearsightedness and farsightedness have decidedly different effects on near work. See the section on behavioural effects of vision to learn more.

Visual Signal Processing – Making Sense of What Is Seen

Once the visual system has acquired the desired visual signal (a word on the page, for example), the brain's visual processing takes over to interpret what is seen into meaningful content. The process of taking input from the eyes and making sense of it before it is sent forward to more advanced and integrated processing is called Visual Signal Processing (VSP, sometimes called visual information processing (VIP), or more simply, visual perception). The process of refining what we see begins in the neuro retina, but this is only the beginning. For example, once a word on a page is targeted and the image is reproduced on the retina in the eye, the brain, starting at the retina, begins to refine the image, applying rules to it in a predictable way to make sense of it. Once that signal (target, word, etc.) is defined visually in the brain's visual processing areas, it is then available to trigger other processes like memory to recognize the word, and the anticipation of what should come next, which relies upon other brain areas. VSP, then, is the visual processing software that helps reproduce visual signals in the brain so that they become useful to other processes, like facial recognition, body movement, reading, and many others.

It is important to note that input from the peripheral retina in the eyes, that is, peripheral vision and information regarding spatial awareness, is required to assist in the next step of visual signal acquisition (VSA) by providing information required to calculate the next movement of the eyes. In this way, VSA and VSP are in a constant 'dance' with one another with the visual system alternating quickly and rapidly between states of central and peripheral awareness. For this reason, learning and reading therapy can and should strive to bolster both VSA and VSP, but also the ability to move mentally between central and peripheral awareness. The elements of VSP can all be trained therapeutically, like VSA skills.

What follows is a rudimentary description of some core visual signal processing (perceptual) elements, but it should be noted that different tests of visual perception will use different referents, some much more complex and detailed. The following are commonly used in pediatric contexts.

1. **Visual Discrimination** – The ability to distinguish differences between objects and scenes to tell if they are distinct from one another. In school, fine visual discrimination is especially relevant early when learning to distinguish letters and graphemes.

2. **Visual Memory** – Consists of not only accuracy of memory, but breadth (how much can be remembered), and duration.

3. **Spatial Relationships** – The ability to discriminate between relative positioning of objects, and the spatial relations between objects.

4. **Form Constancy** – The ability to recognize a visual signal (target) even when it is positioned or represented somewhat differently. When an apple appears to be an apple, even if it is turned upside down, or a letter ‘A’ is still an ‘A’ in a different font, or font size.

5. **Sequential Memory** – The ability to recall visual signals in a specific order.

6. **Figure-Ground** - Figure-ground is the ability to distinguish items of interest from a noisy background, like specific words on a pages full of text, or ‘Waldo’ in a crowd.)

7. **Visual Closure** – The ability to mentally complete a partially completed signal, such as when only a part of a face is visible in a photo, or when only a part of a word is visible.

8. **Spatial Awareness** – Our internal mapping and sense of where we are in the world, and where objects are positioned in space relative to ourselves.

9. **Visualization** – Somewhat related to central, peripheral, and spatial awareness, this is the ability to see in one’s mind the world as it actually exists. This enables motor planning and anticipation.

Some authors include ‘visualization’ and define it as the ability to actively formulate and manipulate visual imagery in the absence of the actual stimulus of the physical signal. This behaviour, and other complex behaviours like reading almost certainly rely on similar neurological underpinnings for the mental recreation and anticipation of the visual signals we encounter. Advanced readers, for example, will not so much *look at words* as *scan text*, searching for recognizable patterns in small collections of words. This sort of advanced skill requires that the underlying neuropsychological building blocks, such as listed above, be fully functional and robust.

Motor Planning

Finally, one critical aspect of VSP is motor planning, which we’ve not discussed. In brief, motor planning relies on the three critical legs of the ‘chair of vision’:

1. Retinal / Ocular Positioning inputs (eyeball proprioception)
2. Somatosensation esp. Proproprioception
3. Vestibular (Balance)

The spatial calculus / planning portion of VSP plays an obvious key role in our abilities to ambulate, write, play piano, hit a tennis ball, play the guitar or prestidigitate. We first develop a motor plan, execute, and then retinal and sensory inputs confirm whether we’ve been successful in our task. The entire process begins with visual input, VSA. If there are any deficits in signal acquisition, motor planning will suffer equal deficits in accuracy and reliability.

In reality, all of these visual perceptual constructs and processes are multi-layered, relying on ongoing CNS input and output. I again refer you to 'Principles of Neural Science' as a primary source if you wish to explore these ideas in greater depth.

Sensory Attention

In addition to the very fine sensory abilities we are endowed with, we have a strong ability to alternate between being generally aware, like being in a state of 'stand-by', and a state of extreme mental and sensory focus. Vision, balance, body sense (touch, limb position), and hearing all can be 'tuned' this way. That is, each is capable of specific and general awareness that may be referred to in other terms, including central (or focal) and peripheral awareness. This is especially so in the case of vision, hearing, and touch. These dual modes of awareness, and the ability to switch between manual control and automatic, extends to our senses generally, but also to our general state of awareness or 'consciousness' on a more global level. We also have the capacity to modulate, or 'change the volume of' some parts of our sensory awareness by paying particular attention to another sense or combination of senses, or by physically blocking the sense through covering the eyes or ears, physical activity, or, finally, by anaesthetic or other modulator of brain chemistry.

People can learn to modulate sensory input through training in self-awareness and self-discipline, such as yoga and simple meditative techniques, but our default behaviour is to respond to, that is 'pay attention to', novel (new or changing) stimuli. So, even in deep meditation, an exploding water heater in the room next door will grab our attention and we have no choice in the matter – what we do after that fact is our choice, but the point is that there is an 'override' in place that is there to protect us, but this override system is important in the classroom. As a further example, if our senses take our attention away from the task put in front of us in the classroom, like someone tapping you on the shoulder, we will need to address that distraction before we can get down to work.

Our senses, then, are available for our conscious use given nothing else is distracting us. Furthermore, all we need to do to 'use' them is simply to pay attention to them – and we can choose between either the central or peripheral elements of each sense, in any sensory combination we choose. Keep in mind that as we pay attention to one sense, we by necessity must pay a little less attention to something else. So, an acrobat is much more aware of her peripheral vision which guides body movement and is not so concerned with her focal (central) vision, but must pay special attention to her central hearing in order to filter out her acrobatic partner's voice hidden in the background noise of the crowd. In the classroom, a child's senses must be especially well tuned to visual and auditory stimuli and these senses must be 'effortless' to use so the child can attend to the higher-level tasks of reading, writing, and mathematics. Many visual impediments, for example, require the child actually pay attention to vision because it takes physical and mental effort to 'work' the eyes and visual processes. The effort (that is, energy) required to overcome even mild or moderate visual impediments to learning (VILs) necessarily takes energy away from other mental processes that should be fully engaged for learning. In more severe cases, the child struggles against vision so intensely that it becomes fully distracting and even leads to emotional outbursts and 'mysterious' medical concerns.

The Neurophysiology of Near Vision

The focusing system consists of the natural lens and a few small muscles inside the front of the eye that tug on it to change its shape. The Edinger-Westphal nucleus supplies parasympathetic fibers to the eye via the ciliary ganglion and controls the ciliary muscle causing accommodation, and also to pupillary sphincter muscle leading to pupil constriction. Sympathetic post-ganglionic fibers also join the nerve from the internal carotid artery plexus in the wall of the cavernous sinus, and these serve to counterbalance the parasympathetic input.

The Edinger–Westphal nucleus also supplies collateral connections to four of six extra-ocular muscles, linking pupillary constriction to accommodation and convergence of the eyes. This is known as the **near triad**. The synergy in the near triad provides the necessary optical response for viewing near objects: The eyes converge to target the near object simultaneously with the greatest degree of visual overlap possible (binocular fusion), the lenses accommodate to bring the object into clear focus, and the narrowed aperture of the constricted pupil acts as a camera's aperture on a higher f-stop providing greater depth of field.

The synergy in the near triad can also work against a child when astigmatism and hyperopia create a constant accommodative strain leading to discomfort, pain, and amblyopia. In some cases, the accommodative impulse is strong enough and persistent enough to lead to esotropia, an inward-turning strabismus, which will further deepen the amblyopia in the turned eye. These cases can be and are often successfully managed non-surgically through visual neuro-rehabilitation.

The accommodative response occurs from the blurring of the retinal image created by effortful viewing of an object of interest. Certain rules apply to gauging accommodative effort.

Astigmatism induces a constant accommodative strain.

- **Astigmatism induces a constant accommodative strain**.
  - This can be significant at values above 0.75 diopters, and especially uncomfortable between 1.5 and 3.5 diopters. Beyond 3.5 diopters, human physiology tends to prefer to not attempt accommodation, choosing rather to simply relax focus and leave the image blurred, thus leading to amblyopia.

Hyperopia requires a constant accommodative response

- **Hyperopia requires a constant accommodative response**, even while looking into the distance.
  - Distance viewing provides the most comfortable vision for emmetropes (neutrally-sighted people). Myopes are comfortable viewing the distance, but the view is blurred.

Myopia requires that the eyes' accommodative response relax for distance vision.

- **Myopia requires that the eyes' accommodative response relax for distance vision.**
  - **Given physiologic limitations of the eye, the ciliary body cannot release enough tension to provide sufficient defocusing to see clearly in the distance. That is, a muscle can only relax so much.**

Nearer objects require an accommodative response as well as convergence of the eyes

- **Nearer objects require an accommodative response as well as convergence of the eyes**.
  - The required visual response increases geometrically with increasing proximity of the object viewed.
  - This still applies to myopia, however myopes begin at an advantage in the classroom because their vision is already tune to near targets.

Presbyopia diminishes accommodative amplitude.

- **Presbyopia diminishes accommodative amplitude.**
  - As children we can generally provide up to 15 diopters of accommodation but strain is still felt at modest refractive errors, especially for farsightedness and astigmatism.
  - In time amplitude diminishes and so we tend to feel strain more often and under more circumstances as we age. If you can see clearly at distance, you will begin to feel strain at near distances in your 40's with accommodative amplitude diminishing to just a few diopters by 50. The ciliary body works just as well as for children, but the lens itself becomes less compliant.

It becomes clear that difficulties with accommodative and convergence responses, or significant astigmatic or hyperopic refractive errors provide a notable disadvantage in a classroom where most work is done within the Harmon distance.

****

Eyesight Vs. Vision — A Behavioural Perspective

To finish this introduction to vision, we will revisit the difference between eyesight and vision, and review basics of refractive error. This time, we'll look at these conditions in a little more depth, and from primarily a behavioural perspective. Refractive error creates a load on vision that the child must overcome in order to even begin to deal with teacher demands. Let's begin by reconsidering the distinction between eyesight and vision — this is critical for a few reasons.

Firstly, the concept of eyesight is the most common public conception of what vision is. It is of course a limited view, but an important perspective to understand, especially when trying to explain why vision has a key role in reading and learning. Secondly, vision can be 'difficult' for many reasons, but in all cases, there are two likely consequences: Discomfort and difficulty finding and targeting objects and symbols of interest. Finally, while the terms 'nearsighted', 'farsighted', and 'astigmatism' are commonly used, not many laypeople will understand the distinction between them. Again, it is not simply a matter of images being 'blurry'. These terms will be revisited later in the context of how they impact reading and learning. For now, we will simply review their basic meanings.

Accommodation

Accommodation, or focusing, is triggered by blur occurring due to refractive errors in one or both eyes, or due to a difference in refractive status between the eyes (**anisometropia**). The focusing reflex is a very low level neural process, but can be modulated through conscious effort, optical correction, and visual therapy. The purpose of accommodation is to bring images into sharp clarity onto the retina. If the eyeball were a camera, the retina would be the film onto which light is focused to make the image clear. The image we are viewing can be focused too far in front of the retina in which case the eye must 'relax' focus to let the image fall back, or the image might be too far behind the retina and the eye must work to focus to bring it forward. As these terms suggest, 'relaxing' vision feels good, and forceful focusing is felt as muscular strain.

Neutral Eyesight (*Emmetropia*)

Neutral Eyesight (*Emmetropia*): The eye's focusing system is tuned for the distance, that is, distant objects are clear with no effort from the focusing muscles inside the eye. As objects are brought closer to the eye, the image inside the eye is pushed back behind the retina, so the focusing system must engage to bring the image closer in, or forward towards the retina.

Nearsightedness (*myopia*)

Nearsightedness (*myopia*): Images in the distance come to focus in front of the retina, and so they appear blurred on the retina. The focusing system must relax to let the image fall back onto the retina, but since the eyes are already fully relaxed, there is no room to move. 'Minus power' lenses help to push the image focus back onto the retina so distance objects can be seen clearly. Nearer objects will appear clear without glasses. Nearsighted people find near work is easy on the eyes, if they are mildly or moderately nearsighted; with no glasses on, they will see perfectly well and in good comfort at near distances. People who are highly nearsighted must bring objects in so close to see them clearly that the eyes must cross inwards, and the arms, head and neck must be manipulated to hold that near posture. Nearsighted children, because they will always struggle with distant eye charts, will almost always be detected by simple sight tests in school.

Farsightedness (*hyperopia*)

Farsightedness (*hyperopia*): Images always come into focus behind the retina, and so the image on the retina is blurred. The eyes must engage the focusing system to bring the objects into clear view, even if the objects are in the distance. As nearer objects are viewed, the focus is pushed further behind the eyes, and so more effort is required to focus to bring the clear image forward and closer to the retina. When farsighted eyes exert too much effort, or for too long a time, the focusing mechanism relaxes, or releases, making images blurry whether they are near or far. In severe cases, focusing requires so much effort that the eyes simply give up trying to focus, and the child is left in a permanent state of blur which leads to amblyopia (sometimes called 'lazy eye'). Because farsighted children can often make enough of an effort to focus, even for a short period, they can often see the small letters on distant and even near eye charts. Farsightedness is a leading obstacle to learning and makes near work especially uncomfortable, but because children can manage to see distant eye charts clearly, they are almost never detected using this technique.

Astigmatism

<u>Astigmatism</u>: In nearsightedness and farsightedness, the problem is that the 'plane' of focus is too far forward of, or too far behind the retina, respectively. An adjustment of focus either with glasses or with the focusing system will move that plane of focus to the retina so we can see the object clearly. In astigmatism, there are two planes of focus, one in front of the other. These planes might both be behind the retina, in front of the retina, or one in front and one behind. In any these configurations of astigmatism, the eye is faced with a dilemma: Which of the two planes of focus should it adjust to see the object clearly? Since the object image is represented on two planes of focus, there is no answer to the question, the eye must try to clear both planes simultaneously. Practically, this means that if one plane is in focus, the other will not be. The end result is that the eye, with the brain's input, must continuously analyse the images and try to make them clear. The constant strain can be both painful and discourage a child from looking at detailed objects, such as letters and words. Distance or near viewing is not the concern with astigmatism, both will be blurred, and both will require effort – all the time, just like with farsightedness. Astigmatism will also cause objects to appear distorted, and this leads to difficult reading and viewing of finely detailed objects. Astigmatism, then, can also lead to amblyopia if not corrected early enough.

Anisometropia

Anisometropia is another condition that is often uncomfortable. Anisometropic refractive errors, such as the name suggests, describes a condition where there is a significant difference in optical properties of one eye compared to the other. One eye might be more nearsighted or farsighted than the other, or perhaps one eye is farsighted while the other is either emmetropic or nearsighted (nearsighted in one eye, farsighted in the other m= antimetropia). There are many combinations of anisometropic errors, but significant anisometropia is relatively uncommon compared to simple astigmatism, hyperopia, or myopia. Moderate amounts of hyperopia and astigmatism can be especially uncomfortable and noxious to reading and learning, while relatively lower amounts of anisometropia can have a similar effect, depending on the magnitude and type of differences between the eyes. Anisometropic differences also lead to differences in image size, called **aniseikonia**, which requires special attention when correcting optically. Contact lenses are a cheap and effective way of neutralizing the magnification differences arising from correcting anisometropia.

Presbyopia

Presbyopia, or literally 'old eyes'. As we age, we lose our ability to pull focus – the ciliary body/muscle can still tug at the lens, but the lens itself becomes stiff and immovable. We all become presbyopic, regardless of our refractive state or history. The simple rule is this: If you have presbyopia and see clearly at distance, then you will struggle to see at near. So, for example, if you use glasses to see clearly at distance, you will not be able to read easily with those same glasses since your eyes cannot pull focus to the near range for you. If you have myopic / nearsighted eyes and your glasses enable clear distance sight, then you are likely to take them off to read. a

Approaches to Measuring REFRACTION

In this next chapter of our discussion on refraction, we'll review the different types of refraction typically referenced and measured in a clinical setting. You'll remember from our last discussion that refraction is the process of determining the refractive offset of an eye. In most cases people will want to wear what is called their subjective refraction sometimes called the manifest refraction. So let's start there.

Going back to our Dictionary of Visual Science,

Subjective r. –
1. (n.) The refractive state of the eye as determined by visual judgment of the patient. (Aside: This is through interaction with the refracting clinician, not simply using an automated machine.)

2. (v.) The act or process of determining the refractive state of the eye utilizing the visual judgment of the patient. The **DELAYED SUBJECTIVE REFRACTION** is a clinical testing technique suggested by Irving Borish to elicit **"greater relaxation of accommodation by step-by-step reduction of an excessive amount of convex spherical (plus) lens power to clarity of a distant test object after all other routine refractive measurements are completed through the previously subjectively determined correction for the refractive error"**. (Aside: What this means is this: Since vision is a neuromuscular act and process, the goal is to come at the visual neuromuscular complex from a relaxed state rather than an overtaxed one. Plus power relaxes vision while minus power lenses (divergent light rays) stimulate accommodation, or focusing, as well as convergence and pupillary constriction.

This delayed subjective refraction was the basic approach I was taught and remains only one of several optometric procedures in the toolbox. Still, the subjective refraction remains the cornerstone of most vision and sight assessments.

The **MANIFEST REFRACTION** –

1. The measured refractive state of the eye when accommodation is at rest, as by fixating a target at infinity, but not paralyzed.
2. The act or process of determining the refractive state of the eye when accommodation is at rest, as by fixating a target at infinity, but not paralyzed.

The **CYCLOPLEGIC REFRACTION** is the

1. refractive state of the eye when accommodation is totally or partially paralyzed by a cycloplegic (agent), typically something like tropicamide or cyclopentolate.
2. The process or act of determining the refractive state of the eye when accommodation is totally or partially paralyzed by a cycloplegic.

Given that vision is a process driven by complicated and coordinated muscle action, it shouldn't be surprising that visual fatigue is rooted in these same muscle systems. Importantly, the ciliary body is implicated in eye strain: It's the muscle that controls focusing of light by changing the shape of the lens. Like anything in or on the eye, small things can feel like a big deal and so small bits of excess ciliary strain to gain or maintain focus can feel like great strain. Eyes that are straining to see clearly will not have muscles that can relax for measurement. In many cases, a cycloplegic is used to relax muscle tone in the ciliary body to enable a more natural measurement. Likewise, the change in refraction from a 'dry' state compared to a 'wet', or 'cyclopleged' state, can be very illuminating. In some cases, there is so much muscle strain from cilary body overload that the application of cyloplegic drops and the release of that tension can cause temporary loss of consciousness and a great relief from chronic discomfort – not unlike Botox in that sense.

Objective Refraction

Finally, let's consider the **OBJECTIVE REFRACTION**. This would be a measuring of refractive state by retinoscopy or by automated means where the patient / client says nothing while fixating near and far targets. The auto-refractor strips we use in this course are all good examples of objective refraction. Since we humans are living beings with muscle systems adapting to environmental and task needs, no one machine reading could ever be considered an adequate assessment of the refractive state. Just remember, it's a classic error to buy glasses based on a machine reading alone.

That's it for now on the different sorts of clinical refractions. Let's move on to have a look at the refractive states starting with Emmetropia, that is to say, neutral sightedness.

EMMETROPIA

Recall from our last discussions that the act of focusing light take effort, muscle effort, and the coordinated signalling from no fewer than 8 cranial nerves. In this quick lesson, we'll start to look at how to describe the different ways eyes naturally focus light.

In the first video of this series, we defined emmetropia something like the following:

Emmetropia, neutral sightedness, or a 'Plano' (zero) glasses prescription are different ways of describing what might be considered the ideal state of refraction. This state of perfect sight is defined behaviourally as a state where both eyes are aligned and focused clearly on the horizon with no effort whatsoever. In terms of optics we can say that the parallel rays from infinitely far objects are perfectly focused on retinal receptors sitting like a movie screen that is a mere 20mm or so behind the surface of the cornea. Imagine a magnifying lens where you had to place the lens at 2cm to focus the image – that's a lot of focusing power.

Take a minute to watch this brief video on emmetropia from the visionmechanic.net website and youtube channel: https://www.youtube.com/watch?v=Sym-iv8ZBQQ

The structure of the eyeball, or globe, is like a large ball (the white sclera) with a ball one 1/3th this size inset mostly inside of it – this would be the cornea and anterior chamber of the eye. The cornea provides some 80% of the focussing power of the eyeball in young people and this remains fixed – that is, we can't change it at will. The lens, which sits just behind the coloured iris, adds the remaining 20% of focusing refinement and reach.

The 'reach' of focus, that is 'accommodative amplitude' reach declines over time so that people like yours truly, who see fine at distance with no glasses, must rely heavily on near lenses to accommodate for what physiology no longer accounts for. I see fine at distance and have a near-emmetropic refraction, and this means that my dwindling focusing ability means I can no longer ‘pull’ focus in to clarify near targets (pause) text for example is the most tiresome and difficult. This ageing of the focusing ability means that eventually we are left what is essentially a fixed focus lens as I and indeed all of us head into our 40’s and 50s and beyond, like an old Brownie Camera – works for somethings, but not all things.

This ageing of the focusing system is called **presbyopia** (literally ‘old eyes’) and affects everybody, regardless of whether we want to admit it or not, starting in our early- to mid-forties – but the degree to which this is noticed depends on our natural refractive state and what we do for work and leisure. Hunters and outdoor athletes will not be bothered as much by waning accommodative ranges as those who prefer to work with their hands, computers, or reading. Likewise clinical experience overwhelmingly supports that mildly nearsighted people stave off use of near lenses for longer than mildly farsighted or astigmatic people, for example.

Let’s talk about focusing for a minute.

When we focus, we ‘pull’ focus- we move it from a far point of focus to a nearer one. The only way to move focus away from us is to relax the eyes. The problem is that we can only relax our eyes so much. Ideally, we should have to pull focus in slightly, this means that our ideal state of relaxed viewing puts our far point of focus slightly beyond our target leaving a bit of room to pull focus in to perfect the clarity of the scene.

As we view a target at optical infinity (for all practical reasons any distance beyond about 6m or 20ft), the vergence demand, meaning the focusing demand, is zero. As the target moves nearer to us, that demand increases in an inverse geometric way – the closer the target, the greater the relative increase in focusing demand. So, some examples:

1. A target at 2m distance has a vergence demand of 1 / 2 diopters – we need to add a half diopter to sharpen the image, and that comes in the form of muscle effort to change the shape of the lens.
2. At 50cm or 20 inches, that’s 1 / 0.5 = 2D of focusing or accommodative effort to make the target clear once again.
3. At 12 inches, or 30cm, the focusing requirement is now 1 / 0.33 = 3D.
4. Finally, if you’re studying an object at 5cm, the accommodative demand is now 1 / 0.05 = 20D.

The D value, or diopter value shouldn’t scare you – consider it simply the measure of refractive power of a system, or the lens required by a system to make an image clear again. It’s like using meters or pounds, but instead it’s a unit for the light bending power of a lens. The point here is that small changes at near distances make big differences in focusing needs.

As a standard, vision scientists and doctors use the notion of emmetropia as an ideal state. Anything varying from that is often referred to as Refractive Error, or RE. My preference is to simply refer to Refractive State, or simply, refraction. The reason for this is that setting emmetropia as a perfect standard, rather than simply ‘zero’ means that clinically we seek to achieve that – a zero prescription for distance. On the other hand, if everything else is an Error, then we are inclined to deny certain behavioural truths such as the following: A low myopic prescription of say -2.00D means that the eyesight is generally blurred beyond 50cm or so, or about 20 inches. The reality is that this is an ideal natural prescription for computer work and reading – so where's the error there? From a behavioural point of view, it's much better to be 'neutrally sighted' for your primary tasking, so -2D for a desk clerk is ideal and neutralizing that for distance viewing would be an error. -2D for a truck driver would mean they would need to wear glasses to work, but this is an entirely different case scenario – what we do matters when it comes to managing visual needs.

Before we leave this discussion, just a couple more basic terms that can affect anyone regardless of whether they are already nearsighted, farsighted, astigmatic, or presbyopic.

First, there's the notion of ANISOMETROPIA. Clinically, this means the refraction of the one eye is significantly different from the other, namely 1D of difference is technically 'aniso', but behaviourally, we start to notice more binocular dissonance and discomfort at 1.5D or more. Cycloplegic refractions can be helpful in unlocking accommodative and vergence strain resulting from this lop-sidedness in refractions.

Related to anisometropia, but not always present with it, is the possibility of ANISEIKONIA, or a differential in relative magnification of left/right images. This often results from a significant difference, say more than 1D anisometropia, or large differences in astigmatism between the eyes. Often, the effect is only noticed when standard ophthalmics are applied that is, standard lenses – different powered lenses produce differing magnifications. There are ways around this including well-fit contact lenses, and what I like to call 'balanced' lenses by ShawLens.com – ShawLens has automated a process that optometrists like me once spent time calculating out by hand – measuring and calculating lens differences between the eyes to render two lenses that ultimately produce nearly equally sized images.

If images coming from the eyes are of differing magnification, the brain will struggle to fuse the images into a tight single entity. The resulting shifting of transposing images leads to asthenopia, difficulty reading and tracking targets, and the spatial differential can seriously hamper fine and gross motor skills, degrade depth perception, cause vestibular or balance concerns. Like any other significant Visual Impediment to Learning and Development, Aniseikonia is an identifiable and treatable cause of headaches, and learning and behaviour concerns among adults and children alike.

Ok, that's enough about emmetropia, anisometropia, and aniseikonia for now. We know now that neutral sightedness is a state of relaxed vision while gazing at the horizon, and that it takes muscles effort to pull focus nearer to us. We also know that as targets come closer to us, the relative accommodative demand increases geometrically. We learned that refractive state is a measurement, like height, or weight, but the difference is it is a measure of light bending power, the power needed to bend light to make it clearly focused on the retinal receptor cell layer on the inside of the eyeball. This power is expressed in diopters. We also saw that the left and right eyes are not always equipped with the same refraction, that a clinical difference in prescription between the eyes is called anisometropia. A clinically significant difference in image magnification between the eyes can often be caused by putting correcting lenses over top of anisometropic eyes, and this state is called aniseikonia. Anisometropia and aniseikonia can be debilitating unless properly compensated using thoughtful approaches to optics.

Eye Charts

There are a variety of eye charts out there, some are much more technical and accurate for use in research and for medical purposes, while others are designed for use for screenings, with children, and others still are language-independent and may be used even if reading or speaking is not possible. Both imperial and metric charts are used today: The 20/20 notation refers to 20 feet; the metric equivalent is 6/6 which refers to 6 meters, or again, about 20 feet. Details matter when testing visual acuity and the ultimate detail is testing distance, and of course which eye(s) is being tested.

Chart types include (can search for these) *Snellen, Landolt C, Tumbling E's, Lea Symbols, logMAR, Numbers, Broken Wheels, Jaeger, ETDRS*, and others including some dubious apps. Regardless of the chart type, these same principles will apply, so we can use different approaches to arrive at the desired measure. The standard chart, the 'big E' Snellen chart is very old and has been modified over the years, but it remains in use.

Note also: https://indigenouspeoplesatlasofcanada.ca/article/language/
https://montreal.ctvnews.ca/first-ever-inuktitut-eye-chart-reaches-indigenous-communities-in-their-language-1.6347015

Whether imperial or metric, the way they work is the same:

1. The scale will progress (usually) from large symbols (aka 'optotypes', sometimes pronounced 'ototypes') to smaller ones in a regularly spaced and sized fashion. Each of the optotypes should also consist of regularly spaced line elements, where the lines are as wide as the gaps between them. (I personally will often start my testing from smaller optotypes and work to the larger ones, this is frequently faster, less tiring, and it allows me to see how people naturally struggle with smaller characters and symbols.)

2. The top number in the ratio remains constant and indicates which scale is in use, that is, the reference distance – is the test calibrated for 20 feet/6 meters, or 10ft/3m, or closer, for example 40cm/16in.

3. The bottom number indicates the limit of sight (visual spatial resolution) of the individual, and this number will vary from person to person, indeed, it will even vary from left to right eyes.
    a. 20/20 (6/6) would mean that the eye can see 'at 20 feet what others can see at 20 feet'. Technically, it means they can resolve down to 1 minute of arc, at least.
    b. 20/40 would mean that the eye sees half as well as the 20/20 eye. Another way of putting this is that letters have to be twice as big as the 20/20 letters/optotypes to be seen, or the person would have to be twice as close to the letters/optotypes.
    c. Other examples would be expressed as 20/15 (25% better than 20/20), 20/30 (50% worse than 20/20), 20/80 (significant visual impairment, or low vision, and 4x decline from 20/20, requiring letters 4x the size, or reducing viewing distance to ¼). Metric equivalents would be: 6/4.5, 6/9, 6/24. A quick review of these examples reveals them to be a simple ratio between optotype size and viewing distance.

Every viewing distance has an optimal optical arrangement where the eye views the target in a relaxed way, with optimal (not too much, not too little) focusing effort. So in my case, I like a like plus power lens for working at my computer: This is my distance lens prescription plus a little extra boost given the near proximity of my computer screen. Visual acuity declines steadily with not only degree of refractive offset (error) from this optimal optical arrangement, but the nature of the decline itself depends on whether the eye is relatively farsighted or nearsighted vis-à-vis the target. Otherwise said, if our vision requires Key A to see clearly and easily at a certain distance, anything other than Key A will be a problem, more or less, depending on how far off it is from the ideal match. As we will begin to discuss in the lesson on Visual Impediments to Learning and Development, relative nearsightedness has a very different look and feel compared to relative farsightedness, or hyperopia, or astigmatism.

Aside - 20/20 and the Limits of Human Sight

> When we speak of eyesight, we are really speaking of spatial resolution: How much detail can be resolved on a small scale. One way of expressing this is in terms of the density of lines and gaps in one inch. Expressed in science, we expect that a healthy and optically corrected eye should be able to see one minute of arc in detail: A full circle has 360 degrees, so take one of these increments and divide it again into 60, and that will give you one minute of arc. To 'see 20/20' means that the eye and brain can resolve detail down to the level of 1 arc minute (generally and often measured using distance optotypes which are larger than their near equivalents). The letters on the commonly used eye charts divide bars and gaps into regularly spaced intervals, so the bars and gaps have the same width – the assumption is that if you can tell what the figures are on a line on the eye chart, you are able to distinguish between the bars (lines) and gaps at that level of detail. Many people can see beyond this level of detail, to 20/15. Some can go even further, to 20/10 (or 0.5arc sec resolution) but this is very rare.

Glasses Prescriptions and Eye Charts

Introduction

This lesson is the most technical in this course and covers two critical topics: Eye charts and continues the discussion of glasses prescriptions. Eye charts help us to measure one basic element of vision: Sight – the basic measure of how much detail we can see. The glasses prescription describes a mathematical 'recipe' that will be used by an optician to create glasses that, ideally, help the eyes to see better, but as importantly, to view things and target the eyes with greater ease. Optimized sight leads to better reading on the eye chart, so smaller letters and symbols may be read at the same distance. Regardless of state of health and optical correction, there are limits to the refinement of human sight. Sight charts are a fundamental measure in optics, and an important gateway into what the eyes are doing.

Aside

> There are a variety of other manual tests of visual function, including a library of simple tools to assess color vision deficiency in more or less detail (search 'Farnsworth Color Vision testing' among others), others for assessing stereopsis (depth perception), alignment

and posture (positioning of the eyes), and many others. The emphasis here on tests of visual acuity is that these 'eye charts' are so ubiquitous and they are often equated with 'vision tests' rather than for what they are, tests of visual acuity at a given distance – so 'sight' more than 'vision'. The distinction is as important as ignoring your car's engine so long as you keep putting gasoline in the tank. The details matter and ignoring them can and will lead to unnecessary hazards and costs. This section of the book outlines numerous functional elements that contribute to a child's current visual schema, or state of operations, and all are worthy of attention. My own favourite probes are in free space using household implements such as pens, spoons, flames, laser pointers, penlights – and a good clear path of communications with the client so they can express what they are perceiving and feeling.

Also noteworthy is the fact that even while eye charts are perceived as generally simple to administer, they are frequently underused and misused. Testing using visual acuity Charts, or 'VA' charts, can provide much more detail about function to the observant technician, doctor, and therapist than a simple number on a chart. It's important to attend to how the testing is done but also to how the patient/client responds to it: Cheating, squinting, head movements, eye movements, and facial muscle action all reveal details of the client's visual schema, so in other words, how they approach visual stimulus at near and at distance and what obstacles they encounter. Then again, what people do with the results can be misguided - like telling a myope they need glasses for reading, when often times it's nicer for the nearsighted to read without glasses. Finally, if not used, VA charts are of no use whatsoever. Likewise, if sight (acuity) is not assessed both at near and far distances, the puzzle is far from complete.

Glasses Prescriptions

It's a mistake to think a computer or automated system can generate a useful optical prescription for a human. As a doctor and software developer, I can attest to the limits of what even so-called artificial intelligence systems can do with assessment of human visual function. (AI is in development and is not yet a part of our daily experience, not yet, and certainly this is not technology that has appeared in the world of optometric assessment). The prescription itself is an optimized optic, in numeric form, to 'neutralize' or collimate the patient's ametropia, or refractive offset from the ideal - the ideal being effortless clarity viewing objects at distance. If people were telescopes or microscopes, we could reasonably use current technology to neutralize aberrant optics – this is how the Hubble Space Telescope would have been re-collimated when it was found its optics were slightly askew, the application of mathematics to optics. However, since human vision is fluid, and integrates and involves so many internal systems and external factors and stressors, the assessment must include a broad array of tests, observations, and discussions with the patient to ensure the proper solution is derived for the defined task. This solution must include not only the basic refraction (optimized optics to neutralize aberrations and blur), but it also must address needs of vergence, or how the eyes align together, the individual's work needs, differences between the eyes, and health and lifestyle demands.

How the prescription is implemented, that is, what type of lens material is used, the lens's optical layout, positioning around the face, lens finishes, tints, filters – all are relevant to the wearer well beyond the simple numbers we'll introduce below. The previous chapter offered additional detail regarding what glasses prescriptions mean and how this translates to trouble for the affect person. The following is a further review and discussion of refractive state measurement leading to an important example.

Sphere Examples

The basic glasses prescription, which will not always be the same as the contact lens prescription, can be represented as shown here (OD and OS are old school for Right Eye (RE), Left Eye (LE), respectively):

OD: +1.00DS
OS: +1.00DS

This means “Right Eye: One diopter plus sphere. Left Eye: One diopter plus sphere.” This is a prescription for a basic ‘plus one reader’ that you can find in any pharmacy. This may also be the prescription for a one diopter hyperopic eye (a farsighted eye). DS here means ‘diopter sphere’, that is, with no astigmatism correction: In optics, simple farsightedness and nearsightedness need only spherical correction. A more farsighted eye might have a prescription as follows:

OD: +3.00DS
OS: +3.50DS

In this case the right eye is compensated with ‘plus three diopters’ of sphere power, and the left with ‘plus three-and-a-half diopters’ of sphere power. So, the two eyes are farsighted, and the left requiring slightly more power than the right. The following would represent the equivalent nearsighted prescription, so ‘minus three diopters’ of sphere power in the right eye, and ‘minus three-and-a-half diopters’ of sphere power in the left eye:

OD: -3.00DS
OS: -3.50DS

Astigmatism Examples

OD: +3.00**-1.00x180**
OS: +3.50**-1.00x180**

Astigmatism, or optical cylinder (aka a toric lens), has both a power and an angle (known as the axis). The axis is measured as 0 (zero) to 180. You can think of this as an irregular flattening or folding of the cornea which leads to light focusing between two planes, rather than just one. There is a ‘steep’ curve with a higher power, and a ‘flat’ curve with a lower power. In the case above, the flatter curve is along the horizontal, or 180 degrees, and the steep curve is at 90 degrees. This would be similar to a football lying on its side and is referred to as ‘with-the-rule’ astigmatism because it much more common in a younger population.

OD: -3.00-2.00x090
OS: -3.50-2.00x090

In the case above, steeper curve is in the horizontal, and the flatter curve is along the vertical, or 90 degrees – this would be similar to a football standing on its end and is referred to as 'against-the-rule' astigmatism because it is less common.

Auto-refractor Example

The strip below is from an auto-refractor, a computerized estimation of refractive state from a right and a left eye. The device is set to take three readings of each eye and then produce an average:

[REF]		VD:12.00	
	Cyl. Form: (-)		
<R>	SPH	CYL	AX
	+1.50	-7.75	2
	+1.50	-7.75	1
	+1.50	-7.75	2
AVG	+1.50	-7.75	2
S.E	-2.37		
<L>	SPH	CYL	AX
	+1.25	-7.25	3
	+1.25	-7.25	3
	+1.25	-7.00	1
AVG	+1.25	-7.25	2
S.E	-2.37		

<R> is the Right Eye (OD). We'll refer back to this example in an upcoming lesson on Visual Impediments to Learning and Development, but for now, let's simply put it into words:

"The right eye has plus one-and-a-half diopters of hyperopia (farsightedness), and (minus) seven-and-three-quarters diopters of astigmatism with an axis of 2 degrees." This is a very high with-the-rule (WTR) astigmatism.

"The left eye has plus one-and-one-quarter diopter hyperopia and (minus) seven-and-one-quarter diopters astigmatism." Again, this is very high with-the-rule astigmatism. This patient arrived in clinic effectively blind, a preventable but luckily treatable condition in this case.

We say that for both eyes, this is hyperopic astigmatism, so both farsightedness (plus sphere value) and astigmatism combined. Eyes can be emmetropic with astigmatism (i.e. +0.00-1.50x180, known as simple astigmatism), hyperopic with astigmatism, as above the example, or myopic with astigmatism (i.e. -2.00-1.75x180, known as myopic astigmatism). Note in this last example that the sphere value is 'minus', indicating a minus, or diverging lens, so for myopia, or nearsightedness. Once again, the story is somewhat more complicated than this.

Eyeglass Prescriptions

Eyesight, then, can be described in terms of blur, but more correctly in terms of *when* objects appear blurry – distant, near, or both. Approximately 80% of this focusing power of the eye is from the cornea, which is invariant. The remaining 20% of accommodation is from the effort of the ciliary body pulling and releasing tension on the lens, which lies immediately behind the iris. The **refractive error**, otherwise known as the glasses **prescription** is the optical description of the eye's natural image resolving power, that is, its ability to make an object focus clearly onto the retina with no assistance from the focusing system. Correcting for the distance refractive error will provide maximal resolving power at infinity, provided there is no pathology to prevent this.

In optometry, the refractive error is expressed in the following format:

OD: +1.50 – 1.00 x 090

OS: –2.00 – 3.00 x 060

These are the powers of the lenses required to correct these ‘errors’. OD is from the Latin ‘oculus dexter’, meaning ‘right eye’, and OS is ‘oculus sinister’, for the left eye. The numbers “+1.50” and “-2.00” refer to the amount of farsightedness and nearsightedness, respectively. ‘Plus’ is used to denote farsightedness, and ‘minus’ to denote nearsightedness: This reflects the type of lens required to correct for the error. Convex, or outwardly curving lenses are ‘plus’ lenses and will correct for a deficit in accommodation caused by hyperopia – that is, the eye is already stressed for need of constant accommodation, so this is considered a deficit position as accommodative strain is generally unwanted. In the case of myopia, the eye’s static accommodative status is already over-focused with no effort at all, with near object appearing clearly while distant objects are blurred. Myopes start from a natural focusing posture that is nearer to the page than that of their emmetropic and hyperopic peers, and therefore less effort is required to focus on the page in front of them. Since myopes are naturally over-focused for the distance, we must ‘unfocus’ the light by using ‘minus’ power lenses, that is to say concave or inwardly curving lenses.

The second sets of numbers, ‘– 1.00 x 090’ and ‘– 3.00 x 060’ describe the power and ‘axis’, or orientation, of the astigmatism. The axis is measured across 180 degrees, with zero degrees marked as 180^{o} as opposed to 0^{o} for clarity, given they both denote a perfectly horizontal axis. Horizontally and vertically oriented astigmatism is easier to deal with in the classroom than diagonal, or ‘oblique’ astigmatism. The horizontal and vertical varieties compresses letters vertically or laterally, respectively, while oblique astigmatism twists or distorts letters making them more unrecognizable. It has been shown that as little as one diopter of oblique astigmatism will measurably slow reading.

Finally, while blur is important, what is more critical is the effort the eyes must provide in order to create clear retinal imaging. Astigmatism, like farsightedness, not only leads to blur, but causes the focusing system to engage much more frequently and for greater durations than nearsightedness in which the focusing system is most often in a relatively more relaxed state. It is this relative difference in effort of focusing that gives nearsighted children an advantage in the classroom.
In just a few minutes, we’ll review several cases to help clarify what the number mean specifically and more broadly in terms of how these numbers affect daily living and behavioural development.

Bear in mind the following as we proceed:

1. Visual dysfunction, or Visual Impediments to Learning and Development (VILD), can be divided into two broad categories:
    a. Deficits in Visual Signal Acquisition / VSA
    b. Deficits in Visual Signal Processing / VSP (aka VIP)
2. VSA deficits
    a. Are much easier to reliably quantify than VSP deficits.
    b. Are often the cause of VSP deficits (i.e. strab -> amblyopia and saccadic dysfunction)

   c. Have a negative cascade effect leading to worsening or degradation of other VSA and VSP functions.

3. Visual dysfunction impacts downstream systems (read 'higher cognitive, affective, spatial coordination, vestibular, and motor functions'). The effects are often misinterpreted as other non-specific learning or behavioural concerns. For example, some of the most common reasons for headache are rooted in VSA dysfunction. The same can be said for apparent reading and learning disabilities, autistic behavior, even emotional disturbances and outbursts.
4. VSA dysfunction can in most cases be treated successfully, predictably, with all attendant expected downstream benefits, for relatively low cost and generally on a timeline of less than one year with appropriate active and passive therapies.
5. By far, the greater portion of VSA dysfunction is in unmanaged unbalanced refractive 'errors'. Strong visual process, i.e. VSA and VSP, begins with good health, sleep, and a balanced and unburdened visual optical axis.

Advanced Topic: Spherical Equivalent (SE)

The spherical equivalent of a prescription, mathematically speaking, is the **Sphere Value + ½ of the Astigmatism** value. So, the extreme example right eye above (+1.50-7.75x002), a blinding condition, would be written as Spherical Equivalent (SE) of -2.5D (+1.50 – 4 (half of 7.75, rounded) = -2.5). -2.5D, as it turns out, is arguably an ideal refractive state for a student: Simple nearsightedness with a far point of focus of 1/(2.5D) = 0.4m = 40cm, so perfect for desk work. This common approach to 'averaging' out astigmatism is commonly used in research and has likely heavily biased conclusions in many studies. It can also be extremely misleading when assessing a child's needs, as demonstrated in the above example: Based on SE alone, the child in the example above would not be helped and would remain blinded. The details count, more than the convenience of math – spherical values and astigmatism values should be considered separately and in combination when prescribing with neither value being discarded or minimized in its importance.

Prism, Add Power, and Other Details

Prescriptions might also include additional elements such as prism to align or relax the eyes, and a 'reading power' (Add Power) might be included for aging readers or again to relax the eyes. These notations, along with other specifications will appear with written prescriptions and are beyond the scope of this course and lesson.

Refractive 'Error' vs Refractive State

Refractive Error (RE) is arbitrarily taken as any variance from emmetropia – 'neutral' or collimated light from distant targets, viewed with no effort. Distant targets were the preferred standard for most military and scientific standards even though human visual requirements vary greatly depending on tasking and need. The use of the term *error* is erroneous – refractive states and variances are not mistakes, for one. Secondly, the refractive variance may itself be a benefit in some cases, and a burden in other circumstances. A classic example of the latter is myopia, which is very often a benefit for those who work at near distances, or within arm's reach. Likewise, low hyperopia is a benefit to stargazers. The 'error', then, is relative to tasking and lifestyle needs, and should best be referred to as the Refractive State – ideally this should be measured as a function of normal working distance. So, to a low myope of -2D, for example, their refractive state at 50cm will emmetropic (Far point of focus = 1/2D = 0.50m = 50cm). The notion that our reference for refraction is infinity is an artifact from the mid 20th century when our focus, literally, was on the stars. Nowadays, our focus is usually right in front of us, and it has been this way for a growing number of people for the past 100 years, since the great proliferation of public schools, followed by the increased emphasis on computer-based instruction. As a standard, clinicians still refer to an ideal refractive state as one where there is no effort and maximal clarity while viewing distant targets even though this will be erroneous in many cases.

Summary

It takes years to learn how to address individual optical needs because, in humans, the neuro-optical system is complex: Alive, moving, forever changing and adapting. For now, what is important is to know the basics of how to read a visual acuity number, such as 20/20 versus 20/40, and how to recognize certain elements of a refraction when written down: Higher numbers are bad, mostly, with some exceptions like with myopia which can be a benefit for near work. It's important to also remember that the details of a prescription matter, and that we cannot simply erase the importance of sphere or astigmatism through the mathematics of the Spherical Equivalent (SE). We won't dwell on this, but it should provide a brief introduction with keywords to pursue if you are so inclined.