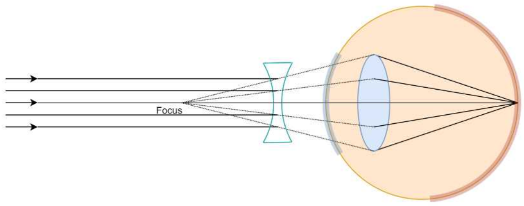

Materials and Methods: Breakthrough Adaptive Theory Predicting Emmetropization Requirements for common Myopia

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0. Methods: Refractive characterization of the eye

The preliminary material included with this article serves as an in-depth introduction for Ray Optics. This article builds upon the basics of the Ideal Lens System (ILS from now on) visualising shifts in observation range from defocus or screen distance changes using Relative Dioptre Scale (RDS from now on).

0.1 Lumped Lens optical consideration of the eye

A labelled diagram[1] of the human eye is given below for reference in Figure 1.

1 Image: Rhcastilhos. And Jmarchn., CC BY-SA 3.0 <https://creativecommons.org/licenses/by-sa/3.0>, via Wikimedia Commons

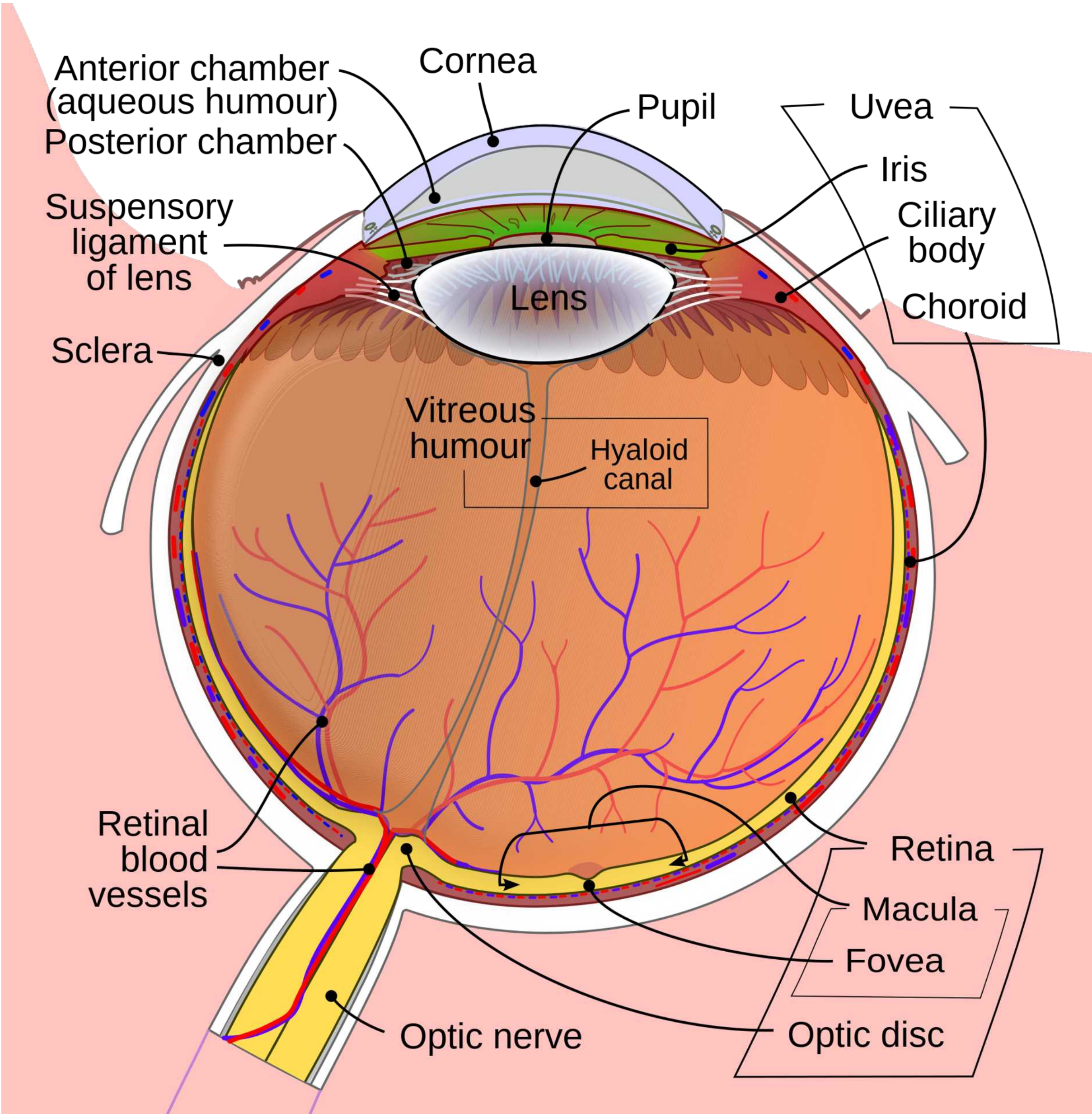

Figure 1 Labelled diagram of the human eye. It shows the lower part of the right eye after a central and horizontal section.

The role ocular components play inside the eye are explained in the order in which a light ray entering the eye traces its path.

Cornea → Aqueous humor → Eye lens through pupil → Vitreous humor → Photoreceptors on the Retina

The Pupil is a hole in the Iris acting as the aperture. The aqueous & vitreous humors act as the optical medium for light travel – changes to the refractive index of any humor results in changes to the focal length, leaving us with remaining components as:

Cornea → Eye lens → Photoreceptors on the Retina

The cornea and the eye lens function as fixed and variable power optical element respectively with the retina acting as an image sensor. The superposition of changes to the ocular components decides refractive power of the eye (converging light rays onto a spot forming an inverted image) just like the ILS[1].

Instead of taking the traditional approach which has historically been attempts to precisely model the complex ocular components, we have chosen to study simpler systems like the ILS for the eye. The primary goal of this article is to quantify observation range changes due to refractive errors. For this purpose, we introduce the abstract concept of a 'lumped lens' having refractive power of cornea and eye lens combined with the accommodation capabilities of eye lens. The distance of retina from the optical centre of this imaginary lumped lens will be referred throughout this article as Retinal Distance (RD in short) and the same can be regarded as the screen distance equivalent of the ILS. Any external defocus/refractive intervention (in the form of glasses, contacts etc.) have to take into account the Vertex distance along other corresponding angular and displacement factors from the optical centre of the lumped lens.

0.2 Observation range of an Emmetropic eye

While the far-point of an emmetropic eye is ideally at ∞, a representative value is needed as the near-point reference. For this article, we have assumed this to be 25 cm without loss of generalisation. It represents the closest distance an adult emmetropic eye should be able to focus continually without imminent fatigue/discomfort under regular circumstances. This value has been represented with a red dashed vertical line at the +4 D mark on the RDS. An elder person might not be able to focus on objects this close due to presbyopia. Throughout this article, the term emmetropic without any prefix refers to *an emmetropic eye without presbyopia* (Accommodation ability ≥ 4 D).

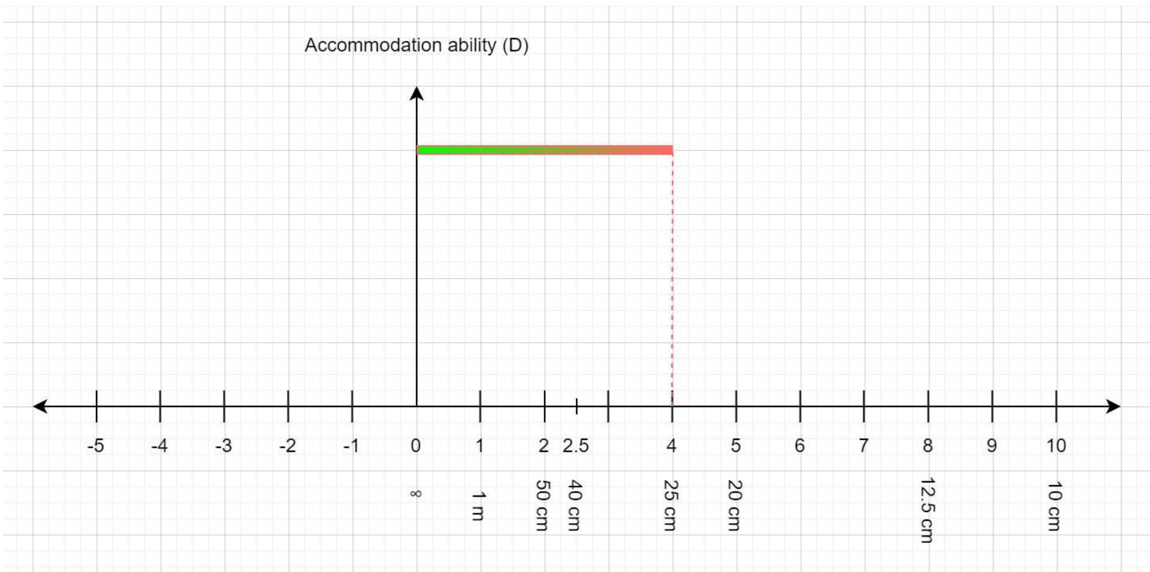

Figure 2: The observation range (25 cm up to ∞) of an emmetropic eye on the RDS

The left (far-point) end of the observation range refers to no accommodation while the right end corresponds to reaching the limit of accommodation. We have chosen to divide the observation range into two distinct regions as shown in Figure 3 assuming a neutral point.

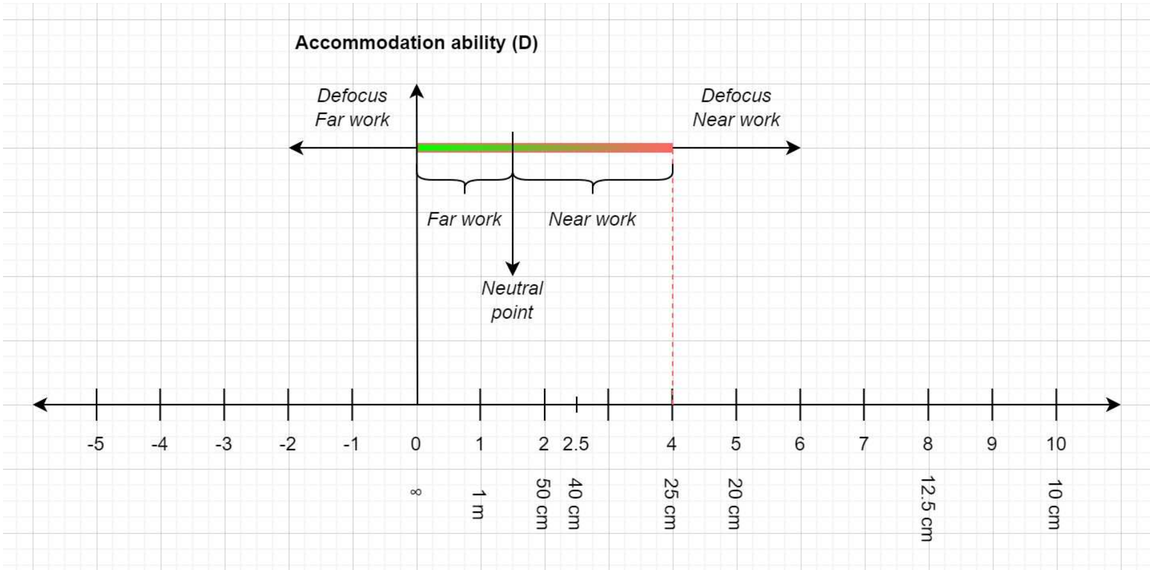

Figure 3 Observation range demarcation in the presence of a neutral point

This neutral point divides the observation range into two parts – corresponding to far-work beyond the neutral point [d_{far}, $d_{neutral}$) and Near-work closer than the neutral point ($d_{neutral}$, d_{near}]. Outside the observation range, defocus distance/far work can be defined as (-∞, d_{far}) and defocus near work as (d_{near}, ∞). These classifications apply regardless of observation range changes. The significance of neutral point will become clearer in the later sections when we will discuss accommodative load.

0.3 Myopia and Hyperopia as the refractive state of the eye

For refractive error, a best possible refractive compensation[2] can be usually determined resulting in a compensated observation range very similar to an emmetropic eye (Figure 2). This best compensated observation range will be referred to as pseudo-emmetropic observation range for the rest of this article.

The refractive compensation can then be 'subtracted' considering the vertex distance from the pseudo-emmetropic observation range giving the originally uncompensated observation range of the eye. Simply put, knowing the properly compensated observation range of a myopic/hyperopic eye, its actual observation range can be determined. Astigmatism, floaters, and aberrations due to retina/refractive media affect final image quality even with best possible refractive compensation in place. Visual acuity/resolution is a property primarily associated with the retina distinct from defocus[3].

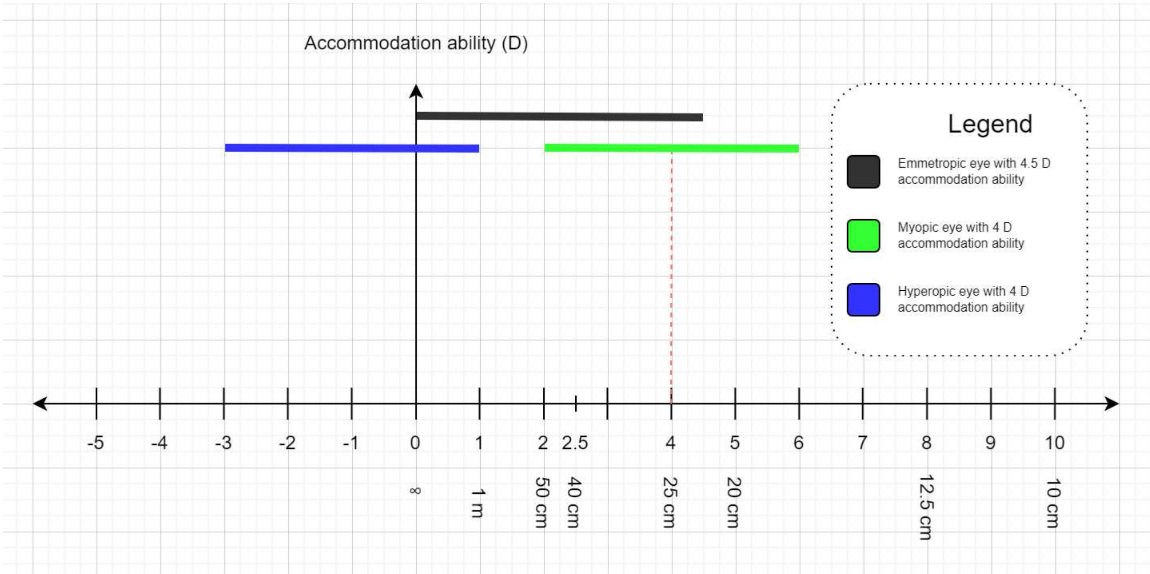

Figure 4 Representing Myopic and Hyperopic observation ranges on the RDS

It can be stated that **Myopia** (green) is a refractive error in which the eyes' far point (the maximum distance at which the eye can **focus**) is closer than and no longer located at optical infinity.

Similarly, Hyperopia (blue) is a refractive error in which the far point is situated 'well beyond' optical infinity resulting in accommodation requirement for focusing at infinity. Hyperopia is much less common than Myopia. Hyperopia/far-sightedness primarily results from changes to the eyeball shape such that images of closer objects are formed behind the retina. Prebyopia unlike Myopia/Hyperopia involves changes to the accommodation ability of the eye. Presbyopia can be also represented on the RDS.

In the lumped lens consideration, both Myopia/Hyperopia result from changes to the lumped lens and the retina. It should be now intuitive to understand how appropriate refractive compensation can restore pseudo-emmetropic state in both the cases. Myopic eyes need hyperopic shift in observation range for emmetropization and vice-versa (Hyperopic eyes need myopic shift for emmetropization).

0.4 Focusing vs. Exposing and Actual vs. Apparent focus

Having already differentiated between image distance and screen distance earlier for ILS, one can extend this distinction for exposing and focusing by the eyes too. This is required to describe for instance, the possibility of an eye **focused** at infinity but **exposed** to a nearby white wall.

An eye (or any optical system for that matter) can be exposed to all physical distances possible but focused only within its constrained observation range. Focusing in this context refers to image distance coinciding with the screen (retinal) distance. Exposure outside observation range results in inability to focus. The defocus due to Myopia results from *exposing* eyes to distances farther than its far-point.

This distinction between focusing and exposing is pretty important to describe what actually happens due to refractive interventions. We will refer to focusing after refractive interventions as *apparent* focus in order to distinguish it from *actual* focusing without refractive intervention. The term **apparent focusing** refers to focusing involving combination of eye with refractive intervention while **actual focusing** refers to unassisted focusing involving only the eyes. Refractive interventions in this context can be said to act as mapping between actual and apparent observation ranges of the eye.

A diagram explaining this for Myopia is given in Figure 5:

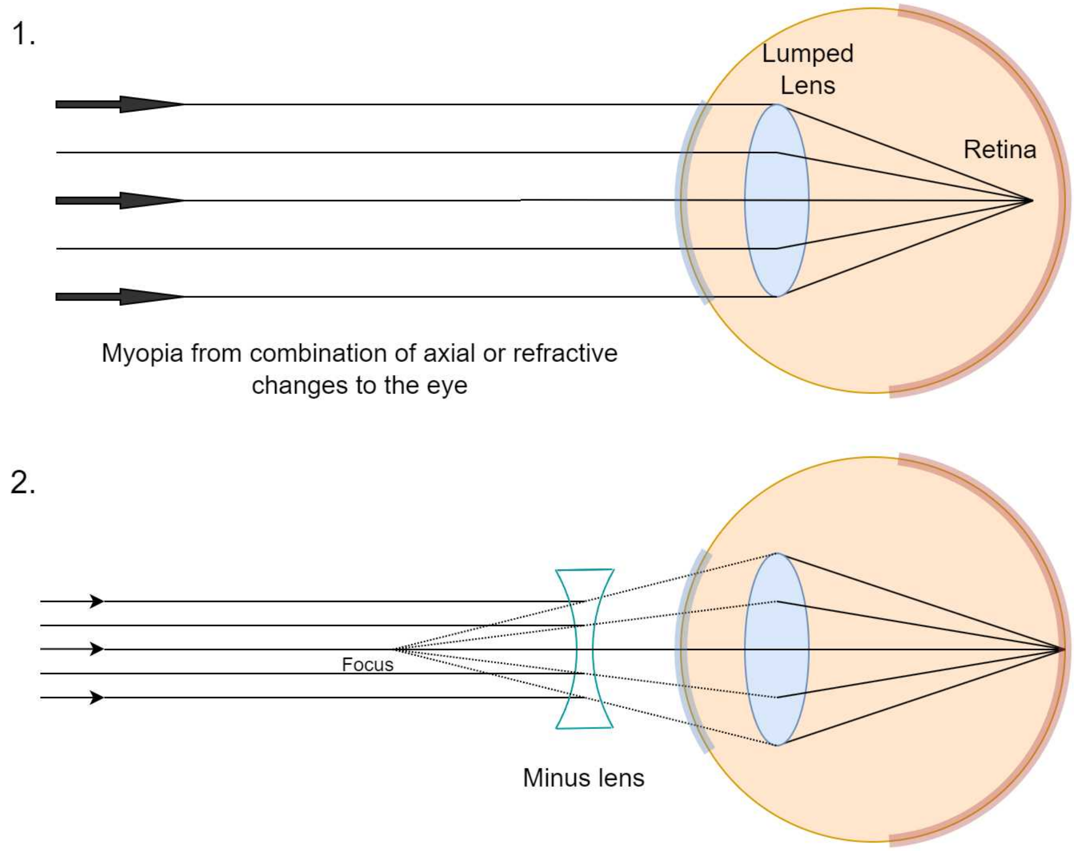

Figure 5 A diagram showing how refractive intervention compensate for Myopia.

In Ray optics speak, the introduced refraction introduces additional divergence to the incoming light rays shifting the resulting image plane to coincide with the retinal plane. It is intuitive to visualize how the compensated myopic eye is actually focused for a distance closer than the apparent focusing distance. For ***apparent*** focus, a myopic eye must actually focus at a distance closer than the said distance and a hyperopic eye must actually focus farther than the distance in question.

1. References

1. Sánchez López de Nava A, Somani AN, Salini B. Physiology, Vision. [Updated 2022 Jul 7]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2022 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK538493/

2. Elliott DB. The good (logMAR), the bad (Snellen) and the ugly (BCVA, number of letters read) of visual acuity measurement. Ophthalmic Physiol Opt. 2016 Jul;36(4):355-8. doi: 10.1111/opo.12310. PMID: 27350181.

3. Ji Hyun Kim, Hye Sun Lee, Na Rae Kim, Gong Je Seong, Chan Yun Kim; Relationship Between Visual Acuity and Retinal Structures Measured by Spectral Domain Optical Coherence Tomography in Patients With Open-Angle Glaucoma. Invest. Ophthalmol. Vis. Sci. 2014;55(8):4801-4810. doi: https://doi.org/10.1167/iovs.13-13052.