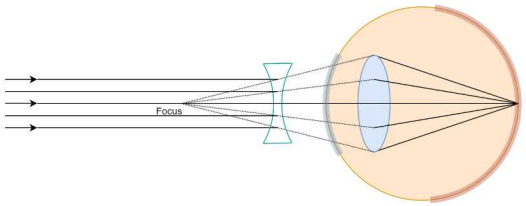

Bright Lighting promotes Active Emmetropization for Physiologic Myopia

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0. Abstract

Purpose: Recent investigations hint towards viability of axial shortening and existence of active emmetropization. In light of these investigations, we propose a novel theory taking into account the interplay between the visual environment and vision habits for commonly observed uncomplicated (physiologic) myopia.

Methods: Survey of the current evidence pool about common myopia on PubMed. The search terms used were as follows: myopia progression, genetics, near work, lighting environment, emmetropization, outdoor exposure. etc.

Results: The resulting Continuous Adaptation Theory (CAT) with its two refractive equivalences, describes physiologic Myopia as a shift in refractive equilibrium between two opposing processes—myopization and emmetropization. Physiologic myopia results from 'push-pull' shift in refractive equilibrium from strenuous incidence of near-work (PULL) along with underutilisation of distance vision (PUSH) causing myopization to dominate. The lighting environment directs adaptation from resulting blur due to defocus, possibly answering the decades-long open question of how eyes deduce the direction of adaptation from defocus.

Conclusions: Our theoretical framework predicts that the environmental stimulus responsible for physiologic myopia onset (in emmetropic eyes) is also responsible for its progression and result from identical pathways. The resulting 'duals' provide valuable insight into slowing/stabilizing Myopia progression and even reducing it toward future emmetropia.

Our Continuous Adaptation Theory develops an indirect (sun)light therapy that holds potential for observing cues of active emmetropization happening leading to first-ever clinically recognizable long-term myopia regression.

0.1 Keywords

Axial shortening, Myopia reduction, regression, Emmetropization

0.2 Conflict of interest & ethics declarations

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0.3 Significance Statement

This text provides the first-ever proper breakthrough toward properly understanding physiologic myopia.

1. Introduction

Myopia is a refractive error widely regarded as irreversible/irreducible with a largely suspected multifactorial etiology[1]. Extreme axial elongation[2] resulting from highly severe myopia increases the risk of vision threatening complications including but not limited to open-angle glaucoma, cataracts, retinal tears that can lead to retinal detachment, and macular degeneration (myopic maculopathy)[3]. An estimated half of the world's population is expected to be myopic by 2050 if the current trends continue[4].

There is an urgent need for viable interventions that can reliably stabilize or at least slow down myopia progression. Existing methods for myopia control have been shown to be incapable of directly affecting the primary consequence of myopia which is posterior axial elongation.

This article describes insights from an adaptive equilibrium characterization for physiologic myopia. The governing insight behind such an approach is recent investigations pointing toward viability of axial shortening resulting in myopia regression together with evidence indicating occurrence of active emmetropization. Our work is in stark contrast with conventional approaches, which are mostly dominated by empirical guesses.

2. Background: Survey of the current evidence pool

Article search for relevant literature associated with non-pathologic/common myopia was done on PubMed. The search terms included but were not limited to:

myopia progression, genetics, near work, lighting environment, emmetropization, outdoor exposure etc.

Particular emphasis was given on articles reporting unexpected findings about myopia.

The background summary follows the natural order:

Binary classification for myopia (physiologic vs pathologic) → Physiologic myopia (onset and progression/stabilization) → Associations of Myopia → Insights/implications from animal models of myopia → Shortcomings of current interventions for myopia

2.1 Physiologic Myopia vs Pathologic Myopia—a strictly modular classification

The term Myopia denotes refractive error resulting in the proper inability to bring distant objects into focus (image formation in front of retina even after relaxing accommodation) compared to an emmetropic eye. Myopia can be further classified on origin basis as physiologic or pathologic[5].

Even high degree of refractive error due to physiologic myopia (increasing risk of sequelae) needs to be strictly distinguished from pathological myopia as well as pathological complications that can accompany highly severe forms of physiologic myopia[6]. Pathologic myopia is often associated with high myopia and complications of the fundus such as degeneration of the macula, optic nerve, or peripheral retina. Nevertheless, signs/complications associated with pathologic myopia (for instance, posterior staphyloma) have been observed to occur in eyes without high myopia sometimes even in otherwise emmetropic individuals[7] *[IMI Pathologic Myopia, May 2021]*.

For this article, physiologic myopia was strictly defined as 'myopia in the absence of other ocular anomalies', except those from axial elongation. This is important from the standpoint of consistent classification—myopia can be either physiologic or pathologic (but not both) in the sense that highly severe physiologic myopia can also lead to pathological complications down

the road. This indicates difference in both the underlying pathways and origin. It is extremely important for pathologic myopia to be perceived differently from just ‘severe form of (common) myopia’. The benefits of this strict classification will become apparent later.

The scope of this article is restricted to physiologic myopia only. The term myopia from now on in this article should be taken to mean physiologic myopia unless stated otherwise.

A list of synonyms for both kinds of myopia is given below (Can be presented as a table).

Physiologic Myopia (of which pseudomyopia is a precursor) - Common, childhood onset, uncomplicated, non-syndromic or non-pathological, functional

Pathologic Myopia—Degenerative, malignant, syndromic

Myopia onset is primarily observed in early childhood, and mostly stabilizes in the mid twenties. The onset of myopia is usually considered as setting the stage for Myopia progression. This translates to a presumed etiology where worsening myopia is viewed as the natural course of disease progression.

However, both myopia onset and progression have been observed at all ages. This is evident from reports documenting adult onset/progression of myopia after enrolling in college[8]. The COVID-19 pandemic also resulted in reports of myopia onset and progression in both adults[9] and school-aged children[10] coincident with lockdown confinement.

2.2 Multifactorial associations necessitating stricter classification for myopia

For several decades, investigations have focused primarily on figuring out the suspected genetic causes of myopia. There are numerous studies investigating the associations of myopia with genetics. However, for physiologic AKA nonsyndromic myopia, evidence is now mounting that at most, there can only be genetic susceptibility in the face of mostly missing heritable markers (‘heritability gap’)[11]. To quote,

“A known genetic factor has been implicated in genesis and development of syndromic myopia (such as Marfan syndrome or congenital stationary night blindness). Nonsyndromic myopia has no clear association with a genetic mutation; however, polymorphisms in different genes are associated with nonsyndromic myopia”.

There are multiple reports outlining the differences between myopia observed to be genetic and one that is environmental. This is unlike the mostly hereditary/parental nature of syndromic/pathologic myopia[12]. Our argument is further supported by the negative association between common myopia and outdoor activity and the recently discovered protective effect of exposure to sunlight[13] on myopia onset and progression.

2.2.1 Environmental and behavioral Associations of physiologic myopia

Myopia shows major associations with environmental and behavioral factors that cannot be explained by genetic considerations alone. On the same note, it is impossible for human genetic makeup to accumulate such significant changes during last half century or so coincident with the increase in myopia.

Eyes, as an organ adaptive toward visual perception implies environmental factors that affect the eyes optically; for instance, object distance (deciding accommodation and vergence), contrast, and brightness/intensity (affecting the pupil) or their superposition are considered physiologic factors. Factors not optical in nature, for instance: hereditary, birth defects/congenital and environmental factors different from those mentioned above such as

toxins, trauma, and other unidentified factors internal to the eye are considered pathological factors.

In regard to common myopia, its cause is commonly predicted to be a multifactorial interplay of environmental and lifestyle factors with a component of genetic susceptibility. Along with an increased incidence of near-work, myopia is strongly correlated with urban lifestyles and higher education. It includes but is not limited to jobs involving dealing with small things (watchmaking, QC&A, for instance); reading, writing and time spent looking at digital displays, whether PC/Laptop/smartphone/tablet[14]. Myopia is not significantly associated with time spent doing near work after adjustment for other factors such as age, sex, ethnicity, parental myopia, school type, and outdoor activity. There were independent associations between closer reading distance (< 30 cm) and continuous reading (> 30 minutes) leading the study authors to speculate that intensity rather cumulative duration of near work was deciding factor for myopia.
This particular study additionally reinforces the need for targeted workplace measures to reduce occupational exposure and mitigations such as allowances for regular breaks from near work[15].

2.3 Animal models of Experimental Myopia and Form Deprivation Myopia (FDM)

Of the large pool of studies documenting experimental myopia in animals, we expect only a subset of observations to actually extend to human eyes.

Both hyperopia and myopia occurred in young chicks when convex and concave lenses respectively were used indicating the ability of the eye to respond and direct axial changes in the opposite direction to compensate for the defocus. Additionally, eyes with myopic defocus (inducing hyperopia) had a disproportionately stronger response compared to similar duration of hyperopic defocus (inducing myopia) as long as the cycle time was maintained longer than 30 minutes[16]. Once the external defocus was removed, progression of experimental myopia slowed and then decreased and in some cases even emmetropia was achieved, suggesting that the built-in mechanism is able to detect and swiftly adapt to changes in external stimuli. The same was also observed in a higher primate (rhesus macaque[17]).

Efforts to induce FDM were successful even after Optic Nerve Section (ONS), indicating that the eye possesses internal mechanisms still capable of directing axial changes (which might also act as a fall back)[18]. This finding was further backed by hemi-retinal form deprivation influencing local axial changes in infant monkeys and chicks before eye-growth is completed. The study on infant rhesus macaques concluded that the effects of form deprivation on refractive development in primates are presumably mediated by presumably retinal mechanisms that integrate visual signals in a spatially restricted manner[19]. These observations are consistent with previous findings indicating that adaption occurs across multiple species, including higher primates (hinting similar possibilities for humans) and that the retina acts as the primary initiator of most localized changes.

2.3.1 Structural modifications caused by physiologic myopia

Hyperopic defocus using minus lenses resulted in the observation of rapid choroidal thinning, indicating AL compensation for the introduced defocus. Choroidal and scleral thinning was most prominent at the posterior pole compared to the equatorial regions of the eye[20].

Human eyes start to develop around the third week of gestation, and the process is mostly completed by the tenth week[21]. Eyes continue to grow rapidly after birth to the age of one to two years and then gradually until adult eyeball size is usually attained around the onset of puberty. The primary goal is to match the eye's axial length with power of its optical components in such a way that images of objects at infinity can be formed with relaxed accommodation

(emmetropia). Eye size and shape at birth influences subsequent eye growth but is not observed to be associated with refractive error development later in life[22].

The distinctive nature of axial elongation in response to external environmental factors separate from eye growth is necessary to explain observed focally controlled ocular growth in infant monkeys and chicks. The eye responds to the superposition of growth and adaptive signals after birth *[Josh Wallman and Jonathan Winawer, 2004]*. Terming axial elongation as eye growth directly contradicts evidence of active emmetropization. Such a mechanism should be present and fully functional in human eyes (although the time period may differ) influencing axial length alongside growth signals[23]. Axial elongation due to myopia results in a marked shape change (elongation) distinct from overall (globe) growth. Hence, we prefer to use the term axial change (for both axial elongation and shortening) instead of axial growth. This approach also avoids irreversible connotations of the term growth, mistaking it for bodily growth of the eyes.

That myopia can be the result of homeostatic control mechanisms inside the eye has been known for quite some time[24, 25]. These observations of structural changes accompanying axial elongation 2.3.1, suggest physiologic myopia shows signs of equilibrium and feedback (characteristic of adaptive systems from control theory). From an adaptive standpoint, myopia progression is shift in equilibrium distinct from stabilized myopia. The observation that myopia onset/progression occurs at all ages strongly reflects that physiologic myopia should also be reducible beyond puberty.

2.4 Shortcomings of existing interventions for myopia

Myopia control/management refers to interventions[26] aimed at slowing/stabilizing myopia progression. This is distinct from refractive interventions such as lenses, contacts and surgical procedures meant to compensate for defocus (after subjective refraction[27]). The term “compensation” is better than the widely used correction in this regard. There can be no difference between refractive compensation offered by glasses, contacts, or refractive surgeries from an optical standpoint.

None of the existing methods truly and significantly affect the physical consequences of physiologic myopia. Currently, there is no widely accepted method directly targeting long-term consequences of posterior axial elongation[28].

The two most commonly used myopia control treatments, Ortho-K and atropine, do not account for or directly address the previously outlined environmental association of physiologic myopia. These widely used management options suffer from frequent rebound effects[29, 30]. Rebound effects after cessation of treatment show that the underlying mechanism and environmental factors behind myopia remain unaffected.

Recent investigations into peripheral defocus strategies (eg. DIMS) echo a shared observation —something other than defocus also plays a key role in myopia[31].

Notably, recent promising advancements in the form of light therapies have reported significant axial shortening beyond measurement uncertainty. RLRL[32] (Repeated Low-level Red Light) and High Environmental Illuminance therapies[33] have shown promise for Myopia management. Light therapies aim to emulate the response to daytime outdoor exposure and its known protective effect against Myopia onset/progression[34, 35]. However, reliable signs of significant myopia regression resulting from existing light therapies have yet to be identified. Further advancements are needed before such therapies can become the standard for myopia management.

3. Continuous Adaptive Theory (CAT)

This section develops a sound adaptive theoretical framework explaining physiologic myopia.

This article utilizes prefixes such as *compensated* to denote an eye seeing with refractive interventions. The symbol ∞ should be taken to mean optical infinity[1].

The problem statements for out theoretical framework are as follows:

1. What are the top factors for physiologic myopia?
2. Arrive at the reason behind lack of a well established cause for physiologic myopia.
3. Why is common myopia considered permanent/irreducible in nature so far?
4. There is mounting evidence contradicting the widely presumed irreversibility of myopia and suggesting the possible existence of interventions that can reduce myopia. The primary goal is to develop a truly viable protocol/method for reducing physiologic myopia.

The underlying hypothesis of CAT is that ocular refraction is governed by homeostatic AKA adaptive equilibrium. The process that makes the eye less myopic/further hyperopic will be referred to as emmetropization, and its inverse will be referred to as Myopization according to our conventions[2]. It also implies that for a hyperopic eye to become emmetropic, myopization must dominate and vice versa.

3.1 Variable time-scale adaptive processes in the eye

Decoding the adaptive nature of the eye involves determining out how adaptive mechanisms inside the eye communicate, delivering images to the retina [*Josh Wallman and Jonathan Winawer, 2004*]. The two ways corresponding to two variables by which refraction is shifted/affected are: focal length or screen distance changes. The focal length aspect is somewhat complicated by two distinct ocular focusing elements inside the eye: – the cornea and the eye lens.

A lot has been already described about accommodation. Accommodation happens to be a very short-term (almost instantaneous) adaptive response decreasing the focal length of the eye lens. The eye lens is unaccommodated while viewing objects at the eye's far point. A high-quality video of accommodation in action[36] can be accessed here: https://youtu.be/1yIpyitm6eE

Long-term axial changes (occurring on a time scale of several months or longer) due to myopia[37] mostly involve changes in the cornea (changes in the corneal curvature and ACD[38]) and thinning of the posterior sclera accompanying physical distancing of the retina[39].

Hypothesis H1: Predicts existence of a medium-term intermediate bridging response between the well-known short-term accommodation and long-term processes associated with axial changes. This intermediate response precedes long-term axial changes to the retina and cornea. In addition to evidence pointing at existence of active emmetropization, H1 is strengthened further from continuous structures of iris, ciliary body and choroid comprising uvea. This medium-term shift should result in marked changes to both the ciliary body and choroid.

Intermediate changes to the ciliary body affecting the ciliary muscle state should result in shifts in the relaxed and accommodated power of the eye lens. The cornea then undergoes long-term changes to alleviate such ciliary shift. In the absence of extensive details, we speculate that observations reporting ciliary body thickening[40, 41] indicate myopic ciliary shift. Thickness changes to the choroid occur in tandem, acting as a precursor for displacement of the retina and

1 10 m (≤0.1 D) or better instead of the usual 20 feet/6 metre

2 Emmetropization should not be confused with the term emmetropia/emmetropic. The former refers to a process (directional context) while the latter indicates refraction of the eye being neither hyperopic nor myopic (positional context).

associated scleral shape changes. Observations describing the inverse association[42] between choroidal thickness and posterior axial changes further strengthen our conviction. We expect these intermediate changes in the ciliary body and choroid to happen mostly before long-term changes are made to the cornea and retina, respectively.

3.2 Changes in refraction/focus range due to myopia

The eye experiences continuous changes while becoming myopic. The ability of the eye to undergo accommodation during this period is roughly constant. A myopic eye continuously gains additional close-range focusing capability while *sacrificing* the ability to observe distant objects compared to an emmetropic eye, as shown in Figure 1.

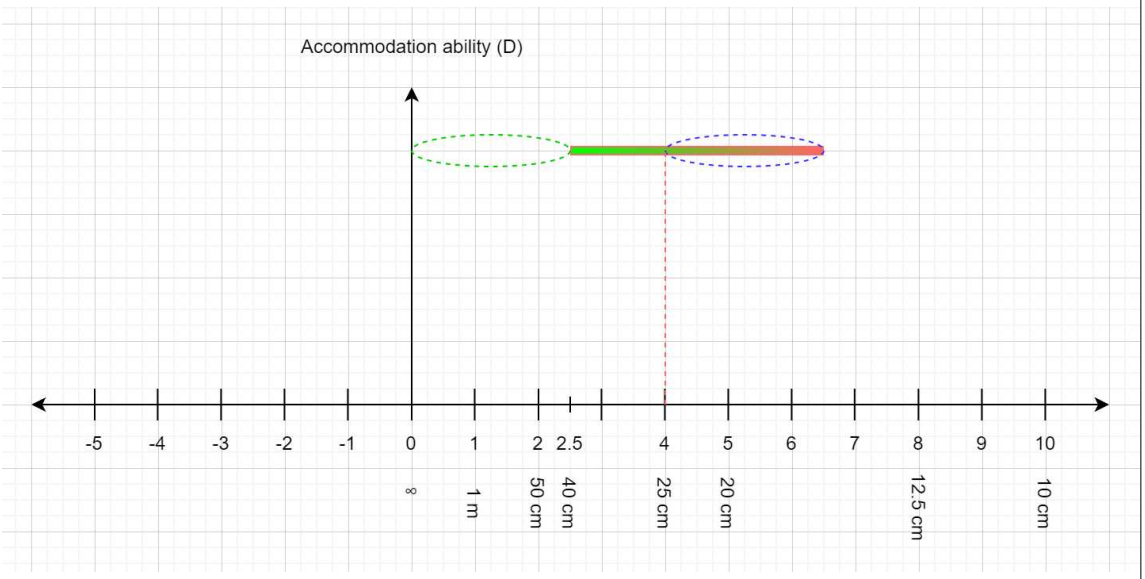

Figure 1 Compared to an emmetropic eye, the gained close-range observation capability by a Myopic eye (2.5 D) is shown with a blue dotted oval while its 'sacrificed' observation range is shown with a green dotted oval. The x-axis scale denotes refraction power/focal length of the eye optics.

The blue dotted oval denotes the gained focusing capability between myopic and emmetropic near points, while the green dotted oval denotes the lost focusing capability between the myopic far point and infinity (its emmetropic counterpart). It is already well known that myopia is associated with both an extended duration of near-work and lack of regular outdoor exposure. This shift in the observation range is in agreement with these well-established associations of myopia and hints at the possibility that both might constitute simultaneous requirements.

Hypothesis H2: Myopia results in the eye gradually gaining extra close-range capability while sacrificing the ability to observe distant objects; that can be explained as shift in refractive equilibrium from increased incidence of near work combined with underutilization of distant vision capability of the eye.

The simultaneous 'Push-Pull' analogy makes this even clearer. It hints that the eye undergoes axial changes trying to relieve accommodative fatigue induced defocus[43]. Due to limited extent of ciliary accommodation, underutilization of the focusing range extrema (here refers to distance vision capability) permits an even stronger response. An increased incidence of near work can be said to exert a 'PULL' while underutilization of distant vision capability exerts a 'PUSH'. The push criteria can alternatively be termed 'permitting' criteria because it allows pull criteria to make myopic changes. A push or pull in isolation should be insufficient toward shifting refractive equilibrium.

H2 explains one of the many unexplained mysteries of myopia: Why does a population not experience myopia onset/progression even with significant near-work incidence[44]? This hints that utilization of distant vision possibly counters adaptive signals from near work and that regular utilisation of distance vision capability can prevent myopia onset/progression. We invite others to verify the physical implications of our explanation. Our finding explains why near-work is correlated[45] with myopia but is not the only factor. Underutilization of distant vision capability (not the same as lack of near-work) is also a contributing factor for physiologic myopia[46].

3.3 Influence of lighting levels and the problem of deducing adaptive direction from defocus

The pupil of the iris[47] evolved as an aperture control mechanism to regulate the amount of light entering the eye. [Pupil size[48] in adults usually varies from 2 to 4 mm in diameter in brightly lit environments to 4 to 8 mm in the dark]. In this context, light intensity affects pupil size in two ways: pupil constricting (bright) and pupil dilating (dim/dark) lighting.

A dilated pupil's shallower depth of field should theoretically demand additional accommodation in dim lighting for unchanged focus distance, translating into hyperopic defocus. Myopization then tries to compensate for this hyperopic defocus.

Moreover, even very forgiving DOF calculations hint that the pinhole effect alone is not enough to explain the dramatic improvements in vision many people experience during daytime. Suggesting the iris must somewhat mechanistically offset the ciliary muscle 'set-point' with its constricting 'tug'. Predicting this mechanistic interaction is also supported by the continuous structure of iris and ciliary body.

3.3.1 Pupil constricting lighting and the role of sunlight in the evolution of eyes

The human eye has evolved[49] from a simple light-sensing structure to a strikingly complex and highly specialized organ dedicated to vision. The scope of this article is limited to pointing out the role of sun as the only primal light source influencing evolution of eyes. By connecting the dots further, it can be understood that human eyes must also show selectivity toward the intensity and (basically black body) spectrum of sunlight. This basically means that the best example of the aforementioned pupil constricting lighting environment is indirect sunlight. For the purpose of this article, indirect exposure to diffuse sunlight will be defined as the sun not directly in the visual field – whether visible directly (incident) or specularly reflected from mirrored surfaces/water/ice/snow.

3.3.2 Deciphering Form Deprivation

It is well known that near work, especially in dimly lit lighting environments is directly associated with myopia[50]. Multiple studies have shown that myopia is the 'default' behavior of animal eyes when subjected to form deprivation in dim lighting environments[[51],[52] and [53]]. Form deprivation has also been successfully induced in higher primates (Rhesus Macaques[54]) meaning a similar response must be present in human eyes as well.

We want to point out that from the standpoint of optics, there is little difference between uniform blur produced by small amounts of hyperopic or myopic defocus. There is only so much information that can be conveyed by image formation alone. The eye must rely on clues other than image formation alone in order to deduce this information. This problem is further complicated by uneven distribution of rods and cones demarcating the central/foveal and peripheral regions of retina[55].

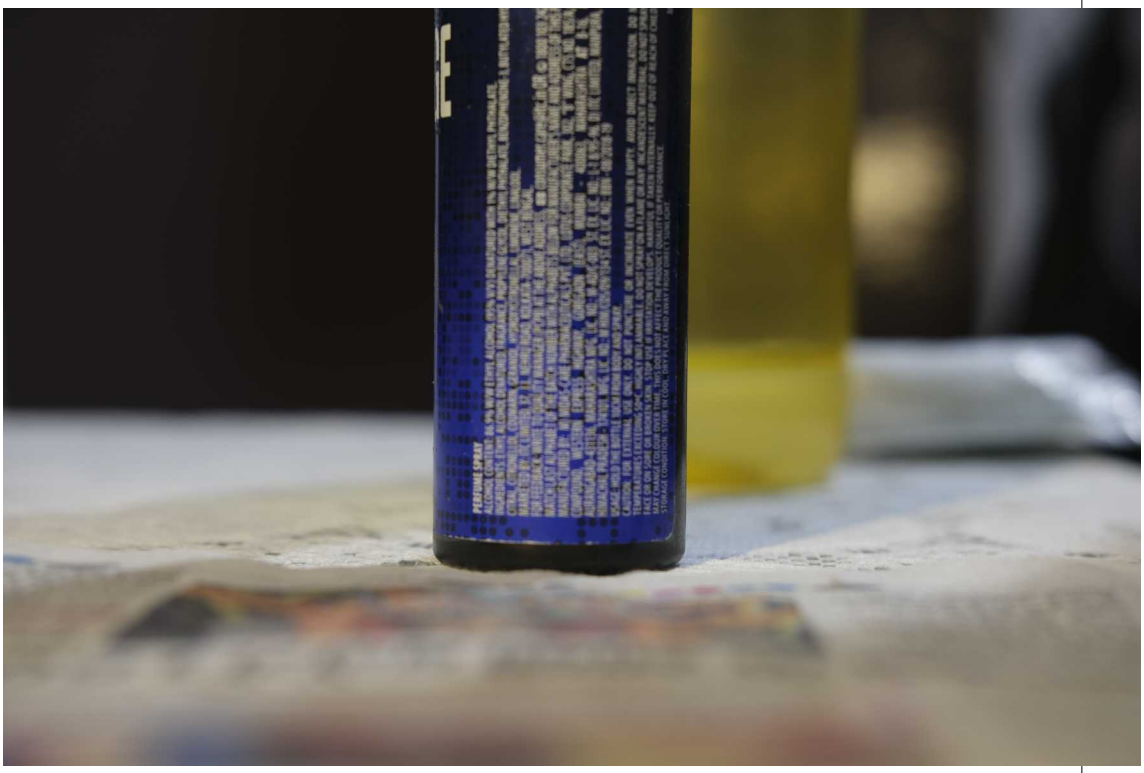

Figure 2 Two images taken at f = 35mm, f/4. Both images demonstrate strikingly similar blur from defocus in central text. Myopic or hyperopic defocus can be determined by checking the lowermost focused part of the image. (Best viewed side-by-side)

This observation alone implies that the mechanism inside the eye responsible for adaptive changes must be much more 'sophisticated in nature' than previously understood. FDM, as an aspect of myopization, also makes evolutionary sense for maintaining refractive equilibrium along with emmetropization. Much debate has taken place as to whether FDM and lens-induced myopia are different[56]. However, our arguments inspire confidence that the mechanisms are indeed the same.

Hypothesis H3: H3 predicts pupil dilating lighting during near-work accelerates myopization by parallel activation of FDM pathways[57]. This is in addition to processes alleviating accommodative fatigue. Form deprivation Myopia is nothing but an essential component of myopization that responds directly to blur from defocus in lens-induced myopia.

It hints that possible efforts toward inducing emmetropization could be rendered ineffective/countered by the dominant nature of the FDM pathway under pupil dilating lighting. The activation of FDM pathway might explain why myopic defocus in primate eyes triggers further Myopization under pupil dilating lighting instead of the expected emmetropization, as expected from animal models.

We previously outlined how accommodative fatigue and underutilization of distant vision capability together shift refractive equilibrium toward Myopia. In this context, less than adequate lighting enhances myopization by parallel activation of the FDM pathway besides responding to accommodative fatigue. Lighting condition happens to be the last remaining puzzle piece in our understanding of physiological factors underlying Myopia[58]. This might also explain why highly myopic people experiencing active myopia progression can show sensitivity to bright lighting environments, which normally do not significantly affect emmetropic individuals. Low lighting conditions also reduce the availability of information, increasing the chances of developing alignment errors and visual aberrations thereby making myopization inherently 'inferior' than emmetropization in this regard.

3.4 Refractive Equivalences for Physiologic Myopia

The similarities between an emmetropic eye and an eye compensated[3] for myopia can be subdivided into two equivalences. These result from simple equivalence of refraction.

3.4.1 Observational equivalence of far-point

The apparent far-point of a pseudo-emmetropic (best compensated uncomplicated myopic/hyperopic) eye is equivalent to the real far-point of an emmetropic eye at infinity. This equivalence cannot always be extended to the near-point due to the variation in accommodation ability and/or presbyopia.

The apparent far-point of a myopic eye with proper refractive compensation lies at infinity. This can be termed as 'clamping' of actual far-point due to refractive compensation, shown in Figure 3.

3 Termed pseudo-emmetropic

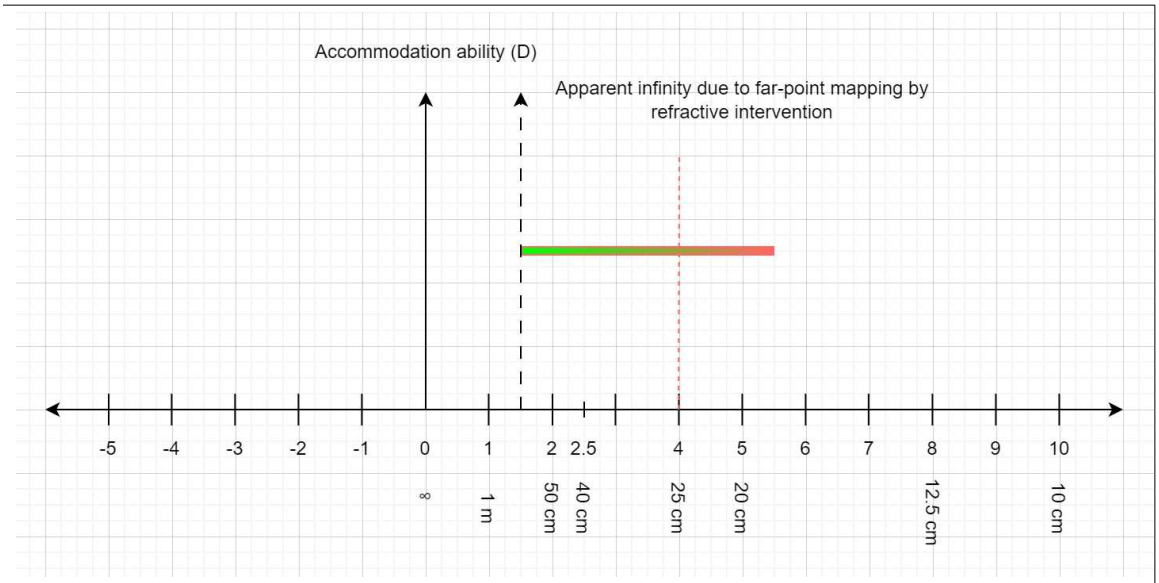

Figure 3 Clamped far-point of a Myopic eye (1.5 D) by refractive compensation

3.4.2 Behavioral/equilibrium equivalence of the refraction shift

Any refractive shift affects identically, both an emmetropic eye (onset of myopia) or an already myopic eye (myopia progression). This equivalence naturally extends to hyperopic shift as well. This basically ensures that any viable method resulting in myopia regression should also cause hyperopic shift in emmetropic eyes.

4. Discussion

4.1 Implications from refractive equivalences

The equivalences outlined in section 3.4.1 basically guarantee the similarity between refractive equilibrium of a stabilized myopic eye and an emmetropic eye. Refraction is in stable equilibrium because the process of myopization is in equilibrium with emmetropization for both (stabilized myopic and emmetropic) eyes, suggesting that conditions for an emmetropic eye to not experience myopia onset is identical for stabilizing myopia. Myopia progression is nothing but 'onset of myopia' in a myopic eye. Even in the absence of a widely agreed upon cause for myopia, these equivalences impose the weaker restriction that constrain the requirements for myopia progression to match with the requirements of myopia onset.

In addition, stabilized myopic eyes shows behaviour closer to a stable emmetropic eye than to an eye experiencing active myopia progression. For hyperopic shift in refraction, myopic defocus is required because ciliary muscle is relaxed for distant work implying the lack of accommodation or accompanying fatigue. Myopic defocus emerges as a necessary but not sufficient[59] requirement for invoking emmetropization. We have already noted the role of pupil constricting lighting in overcoming FDM pathways. It should also explain to why progression of hyperopia unlike myopia progression is very rare[60]!

These equivalences alone signify the urgent need to revisit and properly isolate the behavior shown by stabilized myopia from that shown by progressive myopia in the pertinent literature and explain why efforts to gather insights about myopia from studies on refraction alone failed to yield conclusive insights.

The breakthrough insights from these two refractive equivalences are summarized below in Table 1:

Table 1: Equivalences between a pseudo-emmetropic and an emmetropic eye

Myopic eye with best possible refractive compensation (pseudo-emmetropic)	**Emmetropic eye**
Failure to observe Myopia regression with best refractive compensation even after distance work	No observed hyperopia (shifting of far-point beyond infinity) even after (in-focus) distance work
Myopic shift observed as Myopia progression	Myopic shift observed as Onset of Myopia
Some population reports stabilized myopia even with significant near-work habits.	Some population reports no myopia even with significant near-work habits.
Apparent Far-point is at infinity	*Actual* far-point is at infinity

The refractive state of a myopic and hyperopic eye is as '*valid*' as that of an emmetropic eye from the perspective of CAT. These equivalences combined with the lack of specific retinal complications/anomalies inside the eye should serve to distinguish physiologic myopia from the pathologic kind. Physiologic myopia cannot be termed a disorder or disease. It is a consequence of processes responsible for maintaining refraction in all functional eyes. This is evident from the self-consistency of our adaptive framework and the resulting behavioral equivalences.

4.2 'Genetics' in the context of physiologic myopia

Physiologic myopia is shift in observation range brought by two opposing processes under dynamic equilibrium responding to temporal integration of visual signals. Any influence of genetics on these processes will not considerably alter the processes themselves—rather their rate and consequently the set-point of equilibrium. This is the primary reason why there can only be a genetic susceptibility component for physiologic Myopia, unlike the well-established mostly hereditary nature of pathologic myopia. The observation of FDM across animal species is one of the many hints of physiologic Myopia being an essential/fundamental/functional behavior of the eyes. This also means that basically all human beings with functional eyes can become myopic.

The heredity of myopia is frequently described as myopic individuals having more chances of a myopic parent. After accounting for the possibility that myopic children share a similar environment with their parents, it becomes unclear how much of a role heredity actually plays in the progression of physiologic myopia. It must also be noted that most current studies on parental myopia additionally fail to strictly isolate progressive and stabilized myopia[61, 62, 63] in line with the equivalences in section 3.4. These equivalences outline the urgent need to isolate all physiological variables from pathological ones. We expect definitive trends to emerge when progressive myopia is properly isolated from stabilized myopia in studies.

4.3 Outlining the mechanism underlying physiologic myopia and the feedback loop of myopia

Section 3.1 describes short-term, medium-term and long-term processes that are responsible for maintaining the refraction of an eye in accordance with its visual environment. We have also described how an emmetropic eye becomes myopic in section 3.2.

The onset of myopia is predicted to result mainly from the ciliary muscle 'tiring' out during threshold near-work (also see pseudo-myopia/NITM)[64]. This accommodative fatigue of the ciliary results in imperceptible levels of hyperopic defocus, which eyes try to compensate for by becoming myopic in the long run. Doing near work closer to the focusing limit results in faster exhaustion of the ciliary muscle. Defocus near work predictably results in the superposition of defocus response in addition to extreme accommodation. This myopization route is termed AFiM, short for Accommodation Fatigue induced Myopia. In addition, these findings imply that the eyes can respond to relieve accommodative fatigue in addition to existing observations of eyes responding to the superposition of growth signals, defocus, and pathological factors. The scope of CAT is limited to physiological factors only.

In the absence of suitable interventions, the ciliary body starts adapting to the accommodative fatigue. It is expected that a person with myopic ciliary shift will possess a markedly better ability to sustaining near work for a longer time and suppress near work induced strain signaling. A myopic shift in the ciliary could also result in discouragement toward utilization of distance vision capability in the form of excessive tear formation, rapid uncontrolled blinking, increased sensitivity toward bright lighting and signaled discomfort (HARE[65]), thereby establishing a subtle feedback loop.

Underutilization of distant vision capability in the presence of ciliary body changes then initiates long-term axial changes to alleviate this myopic shift. Subsidence of external factors causing myopia results in equilibrium being established again. The ciliary body gradually returns to its normal state, **preserving** its axial state observed as stabilized myopia.

We have already mentioned that a component of astigmatism should result from increasing angle between image planes at closer distances in section Error: Reference source not found. Another component of astigmatism is expected to result from adaptive anisotropic changes that ocular components can undergo during myopia. The 'recalibration' of the accommodation-convergence reflex as convergence lag mentioned earlier is also predicted to occur alongside myopia.

It is possible that fully compensating for this form of astigmatism may result in discomfort and increase astigmatism (progression). Astigmatism of this form is best left under-compensated unless it perceptibly affects vision.

It is possible that subsequent conflict and recalibration of the accommodation-convergence reflex play crucial roles in influencing reports of initial discomfort associated with major changes in refraction. The common observation of discomfort stabilizing in the span of a few days hints that the convergence reflex is also recalibrated within this time frame.

An important finding from all of these studies is that, convergence also starts becoming significant at much closer distances of near work. A myopic person can always relax accommodation by wearing simple plus lenses or by not wearing glasses for lower levels of myopia but cannot avoid convergence. Prisms are contraindicated because of the potential possibility of disrupting accommodation-convergence reflex.

4.4 Predicted requirements for emmetropization as 'duals'

If physiologic myopia indeed involves a shift in refractive equilibrium, it should be possible to shift refractive equilibrium toward emmetropia. To summarize our findings, section 3.2 covers why accommodative strain from near-work coupled with underutilization of distant vision capability should cause onset/progression of myopia. Section 3.3 outlines why defocus in pupil dilating lighting triggers FDM pathways. Section 3.4 establishes the refractive equivalence between behavior shown by a best compensated myopic eye and an emmetropic eye. A (pseudo) emmetropic eye and an eye with very low myopia should differ only in their ability to focus on distant objects.

For emmetropization, we need to determine the adaptive 'duals' of the factors behind myopization. Implementing these duals need to be augmented with management of near work which can cause myopization. These findings are tabulated in Table 2.

Table 2: Establishing duals of physiological factors required for myopization

Factors resulting in Myopization	**'Duals' for inducing Emmetropization**
Accommodative strain induced hyperopic defocus from near-work (PULL)	Myopic defocus (exposure beyond myopic far-point) (PULL)
Underutilization of the distance vision capability. (PUSH)	Near-work management to reduce accommodative causing Myopization in the first place with convergence. (underutilization of near vision capability) (PUSH)
Myopization is accelerated under pupil dilating lighting due to parallel activation of FDM pathway	Emmetropization requires pupil constricting lighting environment (preferably indirect sunlight) in order to overcome FDM pathways

These duals provide the first ever breakthrough insights into the physical requirements for emmetropization. They expand our explanatory framework, explaining why earlier attempts[66] investigating undercorrection for myopia failed.

The distances beyond the far point (myopic defocus) that need to be exposed under pupil constricting lighting lie inside the green oval for a myopic eye shown in Figure 1. We will refer to this as Actual Distance Viewing (ADV from now on). The benchmark pupil constricting lighting is indirect sunlight on a clear sunny day. Because emmetropization needs pupil constricting lighting, it should also be slightly faster (superior) due to the availability of more information.

This hints that the commonly observed phenomenon of myopia stabilization coinciding with mid-twenties must be linked to changes caused by environmental and lifestyle factors from attaining adulthood and conscious improvements in viewing habits, including eye-strain awareness during increased near work. This also makes it easy to explain adult myopia progression.

The framework of CAT naturally implies that changes from emmetropization should be somewhat countered by myopization due to 'ordinary work' during the rest of the day. This temporal integration aspect hints at a recovery rate less than the predicted recovery rate. The refraction of an eye undergoing myopia regression is expected to follow a stair-step function with slight regressions below baseline, as shown in Figure 4. The time difference between each dip (scale exaggerated for clarity) is the rolling window (which can also be termed the emmetropization window) for temporal integration. This rolling window itself is some multiple of days. Its expected range is 2-4 days for most human eyes.

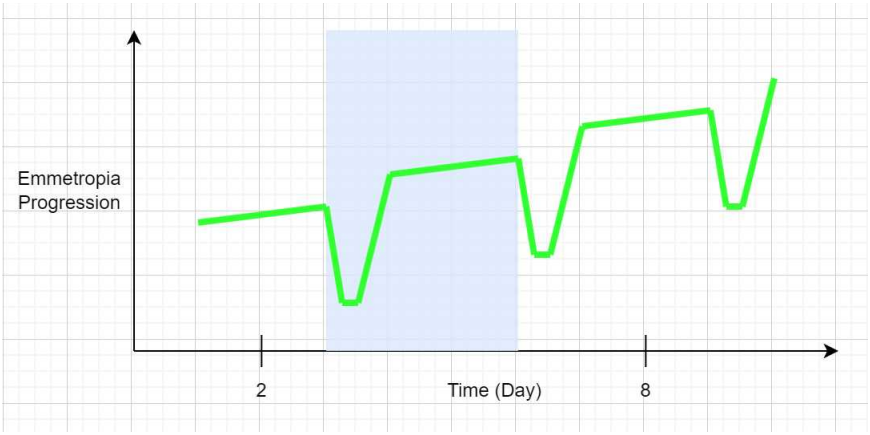

Figure 4: An exaggerated plot of Refraction vs time for fast myopia regression (not to scale)

The adaptive nature of the process also implies that the requirements for myopia regression are stricter than just stabilizing myopia. This happens to be the 'dual' of observing a population subset with significant near-work habits not becoming myopic.

4.5 Changes to the Field of View from Axial Changes

The FoV depends on the screen distance, taken as the distance of the central retina from the optical center of the lumped lens (Combined Retinal Distance [CRD]). Axial length is assumed proportional to CRD. The resulting FoV reduction can then be estimated as *emmetropic AL* ÷ *myopic AL*. This process is similar to how focal length changes affect FoV. For instance, an emmetropic AL of 23 mm and myopic AL of 25 mm estimate a myopic FoV of ~ 0.92× the emmetropic FoV.

One such study considering FoV changes in highly myopic subjects was performed by {Yanming Chen; Ji Liu; Yining Shi} for pathological myopia[67]. On the basis of optics alone, the effects of shrinking FoV should start resembling 'tunnel vision effect' and slight zoom with increasingly severe myopia. This also predicts that people managing myopia regression experience consequent FoV expansion.

4.6 Predicting the duration of long-term axial changes

There are two approaches for predicting the duration of long-term AL changes. Both approaches should converge at similar estimates. The first approach considers that both myopization and emmetropization make changes at similar time scales. By extension, time scale for emmetropization can be estimated from the data on myopia progression[68]. Emmetropization should be slightly faster than myopization because it demands pupil constricting lighting with extra available information.

The second approach involves estimating axial elongation from the degree of myopia and current AL measurements. This is detailed below. For an emmetropic eye, the CRD equals

inverse of focal power of eye focused for infinity. We assume CRD $\propto$ AL, denoting their ratio CRD/AL as β.

The CRD for a myopic eye can subsequently be estimated giving ΔAL, as shown below.

$$\text{Lens relation}:$$
$$\frac{1}{s} - \frac{1}{u} = \frac{1}{f}$$
$$\text{Here, elongated or myopic CRD serves as screen distance } (s)$$
$$\text{and emmetropic eCRD serves as focal length } (f)$$

$$\frac{1}{CRD} + \frac{1}{-u} = \frac{1}{f}$$

$$\text{emmetropic CRD } (f) = \frac{-u \times CRD}{-u + CRD}$$

$$\text{if we assume CRD / AL as } \beta, \text{ where AL is the current myopic axial length, then}$$

$$\text{Predicted Axial Elongation, } \Delta AL \text{ from Myopia} = AL - \frac{f}{\beta} = \frac{\beta \times (AL^2)}{-u + \beta \times AL}$$

$$\text{For instance, a myopic eye wearing prescription of } -4\ D$$
$$\text{corresponding to a far-point of roughly } 25\ cm$$
$$\text{will give } u \text{ as } -25\ cm \text{ for the formula.}$$

If the AL and degree of myopia for a non severe myopic eye are known, this formula estimates Axial elongation provided β remains constant. Measuring the long-term rate of AL changes then provides a rough estimate of the time period required for axial changes.

4.7 Strengths and Limitations of CAT

This article provides a high-level description of physiologic myopia which is a distinct subset of myopia. The proposed framework of CAT might very well be the first such explanation managing to consistently and convincingly explain nearly all clinically relevant aspects of physiologic myopia, including but not limited to its onset, progression and even seemingly irreducible nature in humans.

The strengths of CAT is the novel adaptive equilibrium description of physiologic myopia. The resulting equivalences succinctly explain why studies on stabilized myopes have thus far been mostly an exercise in futility because of their equivalence to emmetropes. CAT is the only description of myopia consistent with the evolution of eyes as a visual organ.

Moreover, we want to stress that the simplistic model upon which CAT builds cannot account for differencess between peripheral and central vision or for other non-physiological factors that can otherwise possibly contribute to myopia. Because CAT redefines pathological Myopia from physiologic myopia, the theory naturally breaks down for pathological myopia due to unpredictable alterations to the underlying adaptive mechanism maintaining refractive equilibrium.

5. Conclusions

The first and foremost conclusion from CAT is evidence favors our explanation that physiologic myopia behaves similar to a process under active equilibrium.

In other words, emmetropization ⇌ myopization for when eyes experience no shift in refraction with time. One of these two processes must dominate to cause a shift in equilibrium. For an eye to experience active myopia onset/progression, myopization must dominate over emmetropization. The opposite must be true for hyperopic changes to the eye.

Our findings also reliably establish that an eye can never be in know of its absolute refraction. The eye only undergoes relative changes based on the quality (defocus) of image formation on retina based on the visual lighting environment.

The theory naturally suggests that myopic defocus implemented strictly under a pupil constricting lighting environment (inducing emmetropization) is the only viable strategy that can result in physiologic myopia regression. The theory obviously predicts adaptive and thus reversible component of axial elongation. Our findings indicate active intervention is necessary to disrupt 'myopic feedback loop' in people experiencing active myopia progression. This is covered in more details in the appendix. We expect the sheer predictive ability of CAT to also provide fast insights into near-work interventions for truly effective clinical myopia regression in the very near future.

5.1 Summing up the Continuous Adaptive Theory (CAT)

A tabulation of the predicted differences between myopization and emmetropization processes is given below:

Table 3: Physiological requirements for factors determining refractive equilibrium

Equilibrium shift by the process	Myopization (Onset/Progression of Myopia)	Emmetropization (Myopia regression)
Visual stimulus 'PULLing' the adaptive equilibrium	Near work accommodative strain resulting in fatigue induced hyperopic defocus. This is exacerbated in pupil dilating lighting environment.	Myopic defocus under pupil constricting lighting that overcomes FDM pathway
Visual stimulus 'PUSHing' the adaptive equilibrium	underutilization of distance vision capability	Near-work management including distancing and periodic breaks as signaled by the eye. (underutilization of near vision)

Accelerator Light levels	Pupil dilating utilizing FDM pathways	Pupil constricting to overcome FDM pathways
Accommodative shift in the ciliary/feedback loop causing shift in Observation Range (far-point and near-point)	Myopic	Hyperopic
Secondary refractive errors	Results in aberrations and progression of refractive errors like astigmatism (inferior)	Corrects aberrations and refractive errors (Superior)
Field of View	Shrinks	Expands
Time Interval	Observed rate of Myopia progression	faster than Myopia progression due to extra light information

Given time and effort, physiologic myopes should be able to approach emmetropia at par but usually better than their current visual performance with the best possible refractive compensation. This encapsulates our bold prediction from CAT, signifying the error-correcting, superior nature of emmetropization.

5.2 Further research

Predicting a concise set of requirements that must be satisfied for physiologic myopia regression presents a massive opportunity for the scientific community.

1. Optimal degree and form of myopic defocus under pupil constricting lighting that safely maximizes the rate of emmetropization. Further optimization of the lighting environment and daytime distant vision requirements.
2. Whether insights from this article can be utilized toward Hyperopia reduction.
3. Experimental studies trying to observe form-deprivation hyperopia under pupil constricting lighting.
4. Further investigations into the role of the mechanistic interaction between the iris and ciliary in the context of the emmetropization.
5. Corporate, industrial and lawmaker roles in promoting myopia prevention guidelines for near work jobs.

6. Appendix: Guidelines for observing physiologic myopia regression towards possible emmetropia

The obvious end-goal for any theory capable of consistently and convincingly explaining peculiarities shown by physiologic myopia should be its ability to at a physically viable method resulting in verifiable reduction of Myopia. The following sections describe the implementation details for the same based on CAT.

Most of the implementation details regarding Myopia management in this section are the result of limited scale experimentation spanning more than a year including the time spent documenting and writing this article. It would have been near-impossible otherwise to gather important insights from theoretical deliberations alone.

6.1 Saturation time concept for emmetropization

The question of the ideal time for exposure (exposure = intensity × duration) to myopic defocus in pupil constricting lighting to induce emmetropization comes from observed peaking of AL reduction (referred to as saturation from now on) around 50 minute mark[4].

"The first statistically significant reduction in axial length occurred after 40 minutes of exposure to myopic defocus, with a mean reduction of −8 ± 9 μm (p = 0.017). This change peaked shortly after, reaching a maximum axial length reduction of −10 ± 8 μm at 50 minutes (p = 0.001)."

We recognise that the article in question is not a long-term study on axial changes. But even then, saturation and its expected duration around an hour holds. The peaking of AL changes in itself is an obvious indicator that the eye takes periodic breaks. The time to achieve saturation naturally increases if attempted in smaller time chunks. Myopes willing to maximize results should ideally aim for an observation time > saturation time. For preliminary trials in the absence of any prior long-term experimental data, the tentative duration of exposure time to maximize saturation can be taken as one hour (more than 50 min). They should be encouraged to determine long-term saturation time on their own as signalled by their eyes. It is possible for time to saturation to extend as eyes adapt to emmetropization.

6.2 Implementation details for ADV

Having described saturation and near-work management aspects in previous section 6.1, we will now elaborate the physical requirements for ADV – myopic defocus under an outdoor indirect sunlight environment inducing emmetropization as per section 4.4.

6.2.1 Duration and routine requirements

Due to lack of previous experimental data regarding time requirement between ADV sessions, myopes should attempt ADV sessions outlined in section 6.1 on an everyday basis until saturation. Effective Myopia regression requires augmenting daily ADV sessions with proper refractive intervention and near-work management guidelines for the rest of the day.

6.2.2 Guidelines for Myopic defocus during ADV

The lack of prior experimental data also implies that the ideal amount of myopic defocus during ADV is in dire need for determination. It is even more probable for effective myopic defocus to vary from person to person. It is also possible for a 'saturation' criteria to exist resulting in the eyes hitting an improvement limit once defocus is more than some threshold.

4 Delshad, S., Collins, M.J., Read, S.A. et al. The time course of the onset and recovery of axial length changes in response to imposed defocus, 2020

This leads us to suggest that non-severe myopes should do ADV without refractive compensation. Attempting ADV without wearing any glasses or contacts results in simpler overall implementation. ADV without refractive interventions directly stimulates emmetropia (ensuring direct exposure to final outcome of emmetropization). Myopes experiencing initial difficulties can and should gradually taper their refractions utilising their former reduced prescriptions if available.

6.2.3 Requirements for distance viewing

As it stands, ADV demands exposing entire visual field to distant contrasting calibration 'targets' under myopic defocus until saturation everyday. The idea behind exposing entire visual field to distant calibration 'targets' emerges from the concept of conveying maximum information. One should never view the Sun directly because the Sun is a point object in the visual field even if one ignores the harms[69] direct sunlight exposure has on the eyes. It is imperative to keep the Sun behind back at all times to minimize risk of harmful UV exposure.

Regarding observation of distant sunlit objects, there is no special demands/emphasis on the way distant objects are to be observed. They should strive to observe objects in a casual, relaxed manner without squinting, forcing or stressing their eyes in any manner.
It is occasionally helpful to shift gaze using extraocular muscles instead of neck muscles, but there is no need to overdo it. There should be no difference from how emmetropes normally observes distance objects. The best analogy is like trying to read a distant signboard or resolve fine details presented by a contrasty distant structure (tree, building, field etc.). Myopes can attempt slow walking, standing, or sit per their convenience. We expect contrasting patterns in both vertical and horizontal meridians to be useful and implore researches to explore and further narrow down synthetic distant target patterns for ADV.

Figure 5 Image demonstrating close to ideal calibration target for ADV

An image showing ideal ADV environment satisfying our criteria is shown in Figure 5. The Sun in clear sky is behind the observer in this image and most of the objects are >20 m away with the farthest being more than 100 m away comprising a good calibration target. The difference between an object at 4 m compared to an object located at 20 m is 0.2 D, a distinction that becomes important for low myopia.

Because the lighting requirement is only for the eyes, being under direct sunlight or doing it from a shaded place is immaterial. The outcomes should be independent of whether the body is exposed to Sunlight or not. People during hot weather conditions should attempt ADV from a cool and shaded place to combat the sweltering heat outside and vice-versa. In summer months, it additionally helps to prepare for extreme sun with sunscreen and appropriate head wear. Swamp (desert) coolers are also effective to combat summer heat in this regard.

It remains to be seen how the strategic requirements posed by ADV pans out for myopes living in inclement climatic conditions receiving little sunlight throughout the year. Artificial lighting that recreate the bright daylight environment might prove useful according to recent suggestions.

NBK470669:

“In countries where the intensity of outdoor light is generally lower, because of air pollution or short duration of natural daylight – such as Canada or Scandinavia in the winter, or Beijing year-around – sunlight therapy could be supplemented in the form of SAD lights (approved and used for Seasonal Affective Disorder)”

6.3 Near work Guidelines for the remainder of the day

We have already established experimentally that observing objects closer than the myopic far-point with refractive intervention requires focusing at a closer distance compared to viewing directly. For myopia, this translates to additional accommodation for viewing the same distance with refractive intervention.

Myopia reduction demands managing accommodation and convergence from near-work as much as possible. This forms the ‘additional requirement’ part for reducing myopia instead of just stabilising it (Section 4.4). Near work load can be mitigated in two ways – reducing the time or by increasing near-work distance reducing accommodation, either physically or refractively. The former can be achieved by reducing near-work time. It is undeniably the most effective but largely impractical approach.

This establishes the importance of taking regular relaxing breaks as indicated by the eye and utilizing distance vision during those breaks. The already established recommendation[70] in the form of 20-20-20 rule is useful in this regard. Refractive means of reducing accommodation need include wearing slight ADD/reading glasses.

For near work, efforts should be made to avoid any and all *convergent* near work < 30 cm. Proper distance for near work must always be maintained. For instance, even if a 4 D myopic person is able to do near work relatively comfortably at 25 cm, it should be considered inferior to near work with slight refractive intervention but requiring lesser convergence.

This should also imply that glasses for mild to moderate Myopia to be worn on a need basis – only for visual requirements farther than the myopic near-point. An exception can be made for severe astigmatism requiring compensation at all distances.

In accordance with our duals established in section 4.4, proper refractive interventions can ensure that the subject’s quality of life remains largely unaffected by requirements of managing near work.

For Myopia management, worn glasses emerge as a clear choice because they are easy to wear and remove in accordance with varying refractive demands during the day; cheaper, reliable, safer, and allow easier management in the longer run compared to contacts.

Within few weeks of daily ADV sessions, it should be expected for an eye to gradually start experiencing difficulties both while wearing their former full scale prescription during day

(development of hyperopic shift) and subtle aversion from near-work. This should result from gradual disruption of myopic feedback loop during initial few weeks of ADV sessions. The recommended course of action is to implement refractive interventions in the order in which they become apparent. Subjects should introduce changes one at a time and that too only when indicated by the eye so fall back options are maintained.

The disruption of myopic feedback loop from ADV sessions also means that refractive demand of the eye becomes somewhat complicated. In such cases, the signalled comfort of the eyes should always be prioritized. Eyes can usually signal immediate discomfort for both over and too much under-compensation and the same must be avoided. As long as the worn prescription is kept within this narrow range of comfort according to the signals given by the eyes, we expect myopia regression to continue.

Refractive intervention is an essential aspect and requires strictly individual implementation because of the varying near-work requirements, current degree of Myopia and preference/tolerance towards myopic defocus. It is obvious that proper refractive requirements for a system as dynamic and adaptive as the human eye can not be accomplished using single vision prescription. We have summarised these guidelines in the table below.

Table 4: Tentative Refractive compensation guidelines for near-work management

Working distance	Daytime (Pupil Constricting lighting)	Evening/Night (Pupil dilating lighting)
For ADV until saturation in bright indirect sunlight environment	Preferably without refractive compensation below high myopia.	NA
Other distance vision	Prescription as per comfort preferably with UV protection/Sunglasses	Full Prescription
Near work just beyond the myopic far-point	Under-prescription as per comfort	Prescription according to eye comfort
Near-work done at a distance closer than the myopic far-point (only applicable for below high myopia)	Below high Myopia, people should be able to observe objects closer than their myopic far-point comfortably without prescription. Emphasis should be on maintaining near work distance to minimise convergence.	
Life-critical task such as driving, operating heavy industrial machinery and other dangerous work	Best Possible Refractive compensation ensuring full best compensated visual acuity to prevent incidents ensuring compliance with applicable laws	

regardless of time and distance	

These tentative guidelines are only meant as a starting point for the trial implementation resulting in a slightly more complicated answer for the commonly asked question in myopia – "When should one wear glasses?". It is expected for the eye's refractive demand to change as myopia reduction progresses. The evaluation criteria always prioritizes safety while reducing Myopia and we fully expect some of these tentative guidelines to fall out of favour or get superseded by further experimental insights.

6.3.1 Note on Blue Light Blocking lenses and why they must be avoided

Coming to the type of lenses used, we suggest simple/ordinary lenses without any special coating such as blue light blocking filters because of the reasons given below:

1. Increased costs of lenses that will need to be replaced eventually in the near future as myopia reduction follows.
2. Provides no clinically substantiated protection against Myopization as evident from multiple research attempts into investigating their benefits[71].
3. Nearly every recent computing device with a display already has an inbuilt blue-light reduction/night-comfort feature. [Windows Night Light[72] and Apple Night Shift[73]]. The intended physical purpose of blue-light glasses is already achieved at the source level for nearly all modern computing devices.
4. Blue light lenses are not a substitute for the utility and eye-protection offered by sunglasses under direct sunlight.

6.4 The proposed mechanism behind myopia reduction

Section 4.3 already covers our attempts at hypothesizing how myopization takes place.

This section attempts to describe how emmetropization mechanism works based on our years of observation coming up with the method described in this article. For lower degrees of Myopia, subject should experience only a subset of what has been described in this section.

The initial days of ADV sessions should be relatively uneventful with slow spontaneous onset of brief moments of clarity in vision (referred to as clear flashes from now on) vanishing immediately after blinking with reset time of minutes to hours between clear flashes. This suggests that just like Myopization, the ciliary body is the first to undergo changes according to H1.

Within weeks of regular ADV sessions, besides a perceptible increase in clarity, the clear flashes become both more frequent and longer lasting. This development alone should be enough to conclusively disprove the prevailing explanation that they result from pinhole effect while outside or from formation of tear film[74] on the cornea. Besides diurnal variation in vision[75], subjects can experience transient intervals of blurrier than expected vision on some days. We suspect that it is due to eye undergoing repair/restructuring.

The anatomy of the eye naturally dictates that clear flashes must be the result of transient increase in focal length of the eye lens. In the case of Myopization, adaptive pull can be said to arise from accommodative strain on the ciliary muscle. However, the opposite of this is incorrect because the ciliary muscle is not 'tired or exhausted' in its relaxed state – hence the term overshoot or 'negative accommodation[76]' is more apt. However, the muscle gets tired eventually

and can't maintain 'clear flash' for long. It also explains the commonly reported instances of twitching 'clarity' in myopic people not wearing their glasses experiencing brief flashes of clear vision in pupil constricting lighting.

Within weeks, active emmetropization should result in the establishment of a feedback loop opposite to the previously described myopic feedback loop – resulting in enhanced sensitivity towards accommodative strain/aversion from near-work. Discouragement from near work serves as a reliable indicator of emmetropization. For a person experiencing active myopia progression, this happens after hyperopic ciliary shift is established after undoing existing myopic ciliary shift.

After regular ADV sessions spanning over longer time-frames (months), myopes should be able to experience a perceptible increase in visual acuity automatically when venturing outside on a sunny day – a telltale indication of hyperopic ciliary shift. Long-term axial changes soon follow to compensate this hyperopic response of the ciliary as long as under-utilisation of near vision continues. This should continue translating into improvements to baseline vision with time until emmetropia is achieved.

Confirming observation of hyperopic ciliary shift would cement the bi-directional bridging nature of ciliary shifts for long-term axial changes along with choroidal thickness changes for both myopic and hyperopic adaptations (Hypothesis H1). This alone should be sufficient to confirm that the predicted[77] *active emmetropization mechanism* is no different than the process making hyperopic changes in accordance with imposed visual stimulus. Emmetropization naturally entails ocular re-calibration for distance vision and will result into eventual changes to the eyeball shape in the long-term (months). Relaxing cool sensations and shrinking feeling felt around eyes both during and after ADV sessions are also common.

It is equally important to mention that most of the aforementioned clarity gains after ADV session vanishes swiftly upon transitioning to pupil dilating lighting. This could be looked as a source of frustration upon witnessing the clarity gained during the day vanishing. This observation is so important from the standpoint of light's role in influencing adaptive behaviour of the eye that we predict that it should result from the mechanistic interaction of the iris restricting 'headroom' for negative accommodation (responsible for hyperopic shift and thus clear flashes), explaining loss of clarity under pupil dilating lighting. This can be seen as dilated pupil restricting negative accommodation. The mechanistic interaction of the iris with the ciliary should also be investigated in the context of Myopization[78].

6.5 Precautions, Safety and myope selection requirements

6.5.1 Implementation Criteria

Managing Myopia according to our method requires active intervention into daily lifestyle and myopes must be willing to devote the (an hour or two) of their daily time towards achieving saturation requirements for ADV besides following near work management guidelines for the rest of the day.

The lack of prior widespread experimental data means heavy emphasis on precautions as first line of defence. We insist on limiting beginner trials to **Non-severe** young adults only, having good ocular health without any adverse event history and screened for the presence of risk factors that can interfere with emmetropization. Feedback from non-severe myopes are crucial to improve the trial for severe myopes.

It is important that all myopes exercise caution in the beginning, starting with 'less brighter' scenery first and take regular breaks until photosensitivity goes away after the first few weeks. We expect the majority of myopes to experience excessive-tearing and strong aversion signals from the eyes in the form of eye-strain and minor headache during beginning due to the aforementioned photosensitivity. It is also recommended that observation duration too should be

gradually ramped up towards recommended saturation of at least an hour so as to prevent the possibility of any adverse complications from undue stressing of the eye. In the rare but possible event of persistent eye-strain/twitching, participants should be told to refrain from ADV sessions for few days until the eye has time to recover completely.

6.5.2 Safety of ADV:

The only part of our method making significant changes to the eye comes from ADV. ADV should have a risk profile similar to onset/progression of Myopia because the underlying adaptive process is the same.

We would also like to point out positive sentiments of vision scientists about outdoor therapies like ours that involve High Environmental Illuminance trials: ["Outdoor-light therapy may offer the ideal treatment for myopia. Not only does encouraging children to play outside combat other major health concerns – such as childhood obesity, juvenile diabetes, and depression – but also, light therapy presents little to no serious health concerns or side-effects compared to those of other available myopia-treatments."4

[[

Emergent Controversies around RLRL treatment:

There are multiple studies promising safety profile and tolerance of eyes towards light therapies with light levels far higher than that of indirect sunlight for Myopia control[79]. No serious complications have been reported in RLRL (Repeated Low-Level Red Light) studies with periods from 6 months up to 2 years. A 12-month study even reports improved accommodative function after RLRL treatment[80].

Update: A recent study reports retinal damage in a 12 year old female after 5 months RLRL LASER exposure[81]. This possibly means that full spectrum indirect sunlight is the only remains light source with an excellent safety profile as of now.

]]

6.5.3 Important Warning for personal safety and compliance with applicable laws/regulations:

Myopes need to be made strictly aware of the potential life-threatening dangers of doing critically important work involving life at risk when not wearing best possible refractive compensation. Put simply, safety of personal and other's lives while driving during low-light such as night-time or working in dangerous circumstances including but not limited to operating construction, industrial, or heavy-machinery/equipments should always be prioritized and best possible refractive compensation must always be adhered to strictly.

Myopes are expected to use fair judgement and not jeopardise other's and their own lives. Because ADV involves myopic defocus and significant uncompensated VA reduction is involved, it is only imperative that personal safety must be prioritised and ADV should always be done in a safe environment.

Although this article describes requirements for stabilization/reduction of physiologic Myopia, the article should not be construed as against wearing glasses/contacts or other refractive interventions in general. The primary aim of this article is only to reduce dependence on refractive interventions.

The author recognises the tediously slow and time intensive nature (taking months and years) for myopia reduction. Still, we are firmly convinced of its enormous utility towards slowing/stopping Myopia progression and maintaining post-refractive surgery outcomes until

faster advances become known. We expect that long-term commitment along with habitual and lifestyle interventions are required to become emmetropic – a theoretically simple but practically difficult outcome.

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