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Myopia - A Brief Review. Investigation of +2 D. to +3 D. Reading Glasses to Prevent Myopia

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Abstract

Basic control theory equations are developed showing classical exponential system response of refraction vs. time R(t), with a characteristic system time constant τ [100 days ± 20%] in response to a negative diopter (-) step change of the student's near-point reading environment. The conclusion is that plus (+) Add lenses, of appropriate strength, +2 D to +3 D, used as reading glasses during study, can prevent the development of myopia progression for college students.

Keywords

Progressive myopia, Reading glasses, Bifocals, Progressive Add Lenses (PALs), Refraction, Myopia prevention, Diopters

Introduction

Literature review

Myopia is a complex, multi-parameter, multi-variable problem, as yet un-solved. In a brief 2,000 words or less review as attempted here, we must be careful not to over-simplify the situation. Myopia *per se* is more common than the common cold, and likewise, while it is entirely possible to ease the immediate symptoms, basic practical techniques for preventing myopia advancing is still not well established.

Cheng, et al. [1,2] and Gwiazda, et al. and Hyman, et al. [3-5] present a comprehensive listing of modern studies to date in terms of using (+) Add reading glasses to prevent or slow the progression of myopia. Brown & Berger [6], Brown & Young [7], Schaeffel & Howland [8], Medina & Fariza [9], and Greene, Brown, Medina & Graupner [10] use first order control theory to predict myopia development as a function of time. Thorn, Gwiazda & Held [11] present a mathematical model of myopia development using the Gompertz function. Hung & Ciuffreda [12] develop IRDT, incremental retinal defocus, to explain myopia during the growth phase. Medina, et al. [13-15] and Greene & Medina [16-19] use control theory to explain myopia development, solved with digital and analog computer techniques to evaluate first-order equations. Greene & Brown [20] compare theory and experiment for college age students. Fledelius [21] presents data on college graduates and graduate students, showing that the myopia continues to increase from age 21 to 26. Greene, et al. [22] presents data on myopia prevalence and incidence rates over the age range 5 to 30 years.

Figure 1a and Figure 1b below show the near work demand problem, typical of college students, and the proposed optical solution to the problem, namely, custom reading glasses.

The extensive literature on the subject of myopia can be divided into 5 categories, as follows:

1) Medical research [21,23-25]

2) Hereditary research [26-29]

3) Pressure-volume and stress-strain research [30-33]

4) Laboratory and optical research [13,34-36]

5) Epidemiology research [22,37-39]

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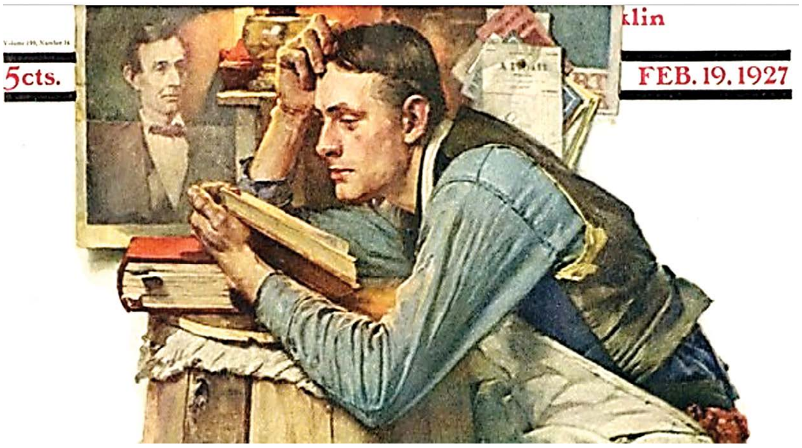

Figure 1a: Norman Rockwell's "*The Law Student", from the Saturday Evening Post*, is seen reading at an effective distance of -3.0 to -4.0 diopters.

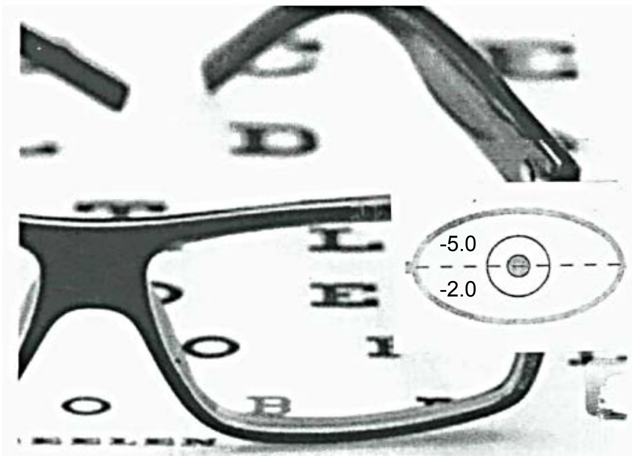

Figure 1b: Reading glasses for a -5.00 D. college myope. (+) Add technology is used by both bifocals and progressive addition lenses, "PAL's". PAL's are "no-line" bifocals. Basically, these (+) Add reading glasses are distance compensators, with a +3.00 D Add for reading.

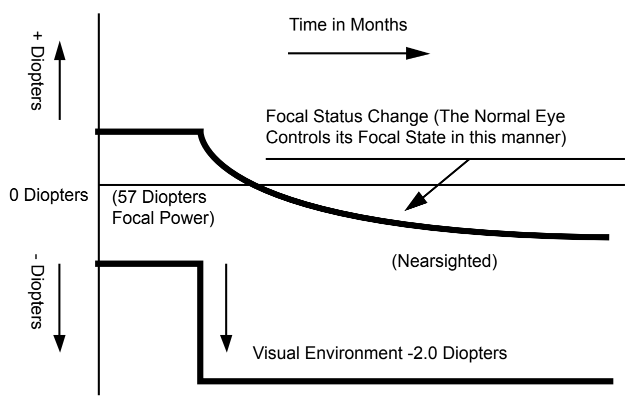

Figure 1c: Time constant TAU = 100 d. ± 20%.

In this report, various mathematical control theories are reviewed, derived from conventional electrical engineering concepts, as shown in Figure 1c.

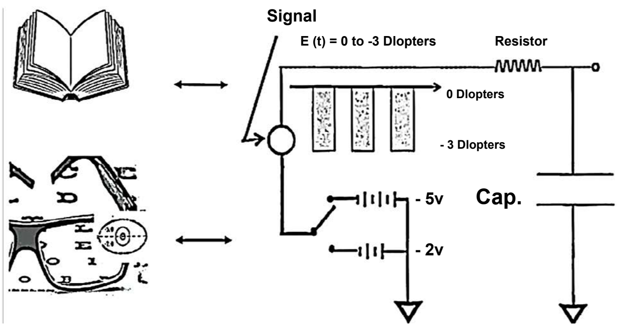

Figure 1d: Solving the basic 1st order differential equations is facilitated using an analog RC computer circuit. Reading a book is equivalent to an alternating -3 volt square-wave, and the effect of distance and near correcting glasses is simulated with a -5 volt and -2 volt battery, as shown. Refraction R(t) as a function of time proceeds exponentially, given by the voltage Vc(t) between the resistor R and capacitor C.

When a strong negative step change is made in your visual environment, normal eyes would change their focal state exponentially as shown in Figure 1d. The optical engineering equations as developed here are the same as used to design the focusing system of an auto-focus 35 mm camera, or even the Hubble telescope, whereby the system senses the average environmental distance (in diopters), responding with an equal adjustment of lens power (in diopters).

Figure 1e and Figure 1f shows the correlation between the eye's focal status [diopters] and the Snellen eye chart acuity as measured, from 20/20 to 20/80.

Material and Methods

The Naval Academy requires unaided visual acuity of 20/20 in each eye as a basic entrance requirement. Prospective pilots are required to have normal vision on graduation. A substantial number of midshipmen, enter-

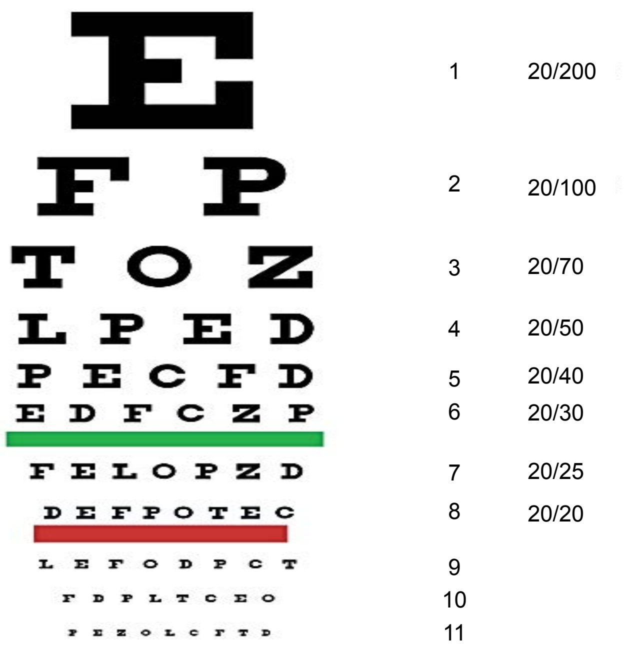

Figure 1e: Typical snellen eye chart.

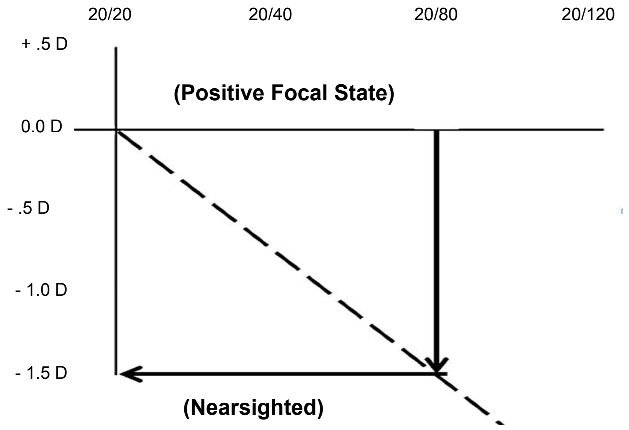

Figure 1f: Visual acuity, measured as 20-20, 20-40 etc., is correlated with refractive error, measured in diopters. As shown, nearsightedness at 20-80 requires a -1.0 D lens to correct to 20-20 acuity.

ing with 20/20 vision, become myopic during their four years at the Academy. A reasonable assessment of the experimental evidence suggests that the eye sets its long-term focus by a servo control process. This engineering analysis of the eye's control action predicts that a significant percentage of midshipmen could avoid the myopia problem is they wear a convex lens while reading.

A positive lens simulates the effect of a distant object on the eye's accommodation system. Prolonged use of this lens for all close work could prevent the development of myopia in the servo model. This neutralization effect of the positive lens has been experimentally demonstrated during a five-year bifocal study conducted by Oakley and Young [40] (Figure 2a and Figure 2b).

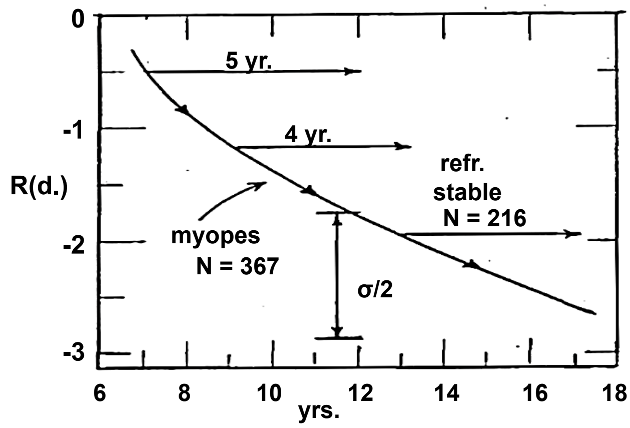

Figure 2a: Assiduous use of the (+) plus lens, over a 4 to 5 year period, can stabilize myopia progression, as indicated by the horizontal lines (N = 216 subjects, N = 367 controls) [40].

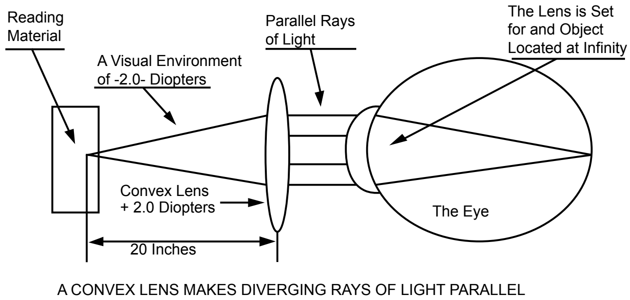

Figure 2b: Static optical schematic to model the reduced focusing demand on the eye with +2 D reading glasses.

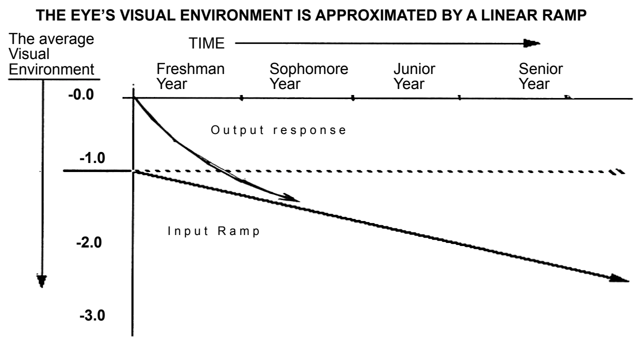

Figure 3: Ramp function A = m t + b.

Results

Average value of accommodation

The controlling variable for this equation is the eye's value of accommodation. The focal settings of the lens is determined by information decoded at the surface of the retina.

The visual environment may be calculated by the use of the equation:

VISUAL ENVIRON = - 1/(OBJECT DIST.) Eq. 6

(in Diopters) (in Meters^-1)

A visual object moved inwards from infinity to one meter constitutes an environment change of -1.0 diopters. Under this circumstance, the accommodation system adjusts the lens by +1.0 diopters to again achieve sharp focus at the surface of the retina.

Average visual environment

The average value of accommodation can be determined if an individual's environment is known on a daily basis. If the individual spends 8 hours outdoors (0 diopters) and 8 hours reading (-3.0 diopters) his average visual environment is -1.5 diopters. The effect of a confined near-point environment can be neutralized or offset by the use of a convex (+) Add lens.

Visual environment of college students

As we enter higher academic institutions, our visual environment gradually shifts to a more negative value, as shown in Figure 3, pertinent to emmetropic plebes (freshmen) at USNA. We can characterize this increased "near" environment by the following ramp function:

A = m t + b, where:

A = Accommodation, daily average value, from the start of the freshman year.

m = -0.001 diopters/day = -0.365 D/yr

t = time in days, b = -1.0 diopters

The Laplace transform of a unit ramp is:

1/(s^2)

Applying this ramp to the eye's transfer function produces:

System's Response = [m/s^2] * [1/(TAUs + 1)]

The eye's time domain response to a ramp function is [30]:

Focus = Offset Accommofstion (Initial Value) (Ramp) + Accommodation * TAU * [(t/TAU) - 1 + EXP (-t/TAU)]

Discussion

Focal status produced by a plus lens

After two time constants (TAU = 100 days ± 20%), this equation predicts that the eye responds with the same slope as the accommodation ramp. We can logically expect that the eyes of college students potentially drift towards myopia when a linear ramp is applied to their accommodation system.

In a study of the cadets at West Point, Dr. Gmelin determined that freshmen with 20/20 vision and 0 diopters focal state would, after four years, develop 20/80 vision with -1.3 diopters of myopia [41].

A similar study was conducted at the United States Naval Academy by Dr. Hayden, reviewed by Greene, et al. [16]. This study showed an approximately linear change in focal status towards myopia in the eyes of almost all the normal eyed midshipmen [33-36]. Figure 1a shows Norman Rockwell's classic painting "The Law Student", from the 1927 Saturday Evening Post, where the student is seen reading at an effective distance of -3.0 to -4.0 diopters. In order to optically compensate for this near-point demand on the system, a -2.0 to -3.0 D lens is used (Figure 1b).

Myopia prevention

We have plotted the typical college development of myopia as a function of time, as shown in Figure 3a. The dynamic theory explicitly states that the eyes of the USNA midshipmen move into nearsightedness due to their increasingly confined visual environment. Their focal status change is in the right direction and proper magnitude to suggest quantitative verification for this dynamic model of the normal eye's long-term behavior.

Conclusion

Work done during the past twenty years has demonstrated that the accommodation system is a superb example of a physiological control system. It is a complex, sophisticated, and accurate system. We can logically expect that the normal eye is similarly competent in the design of its long-term control system.

Appendix I addresses electrical engineering control systems theory, in terms of predicting myopia progression rates <R> [diopters/year], directly related to the intrinsic emmetropization characteristics of each individual. This is a matter of transforming the exponential emmetropization trajectory to the linearized progressive myopia trajectory.

A number of these stated predictions have been tested(+). Myopia prevention is a very difficult task to accomplish. This report hopefully demonstrates that effective myopia prevention is a reasonable expectation, provided the plus lens is assiduously used for all close work [43].

Acknowledgements

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Appendix I: Continuous Correction Myopia Ramp

This Appendix derives the observed "*linear myopia ramp*", frequently reported in the experimental and clinical literature [12,13,42].

The proof that "continuous" or "continual" correction of myopia produces a linear drift of refraction, equivalent to "open-loop" drift, is proven as follows.

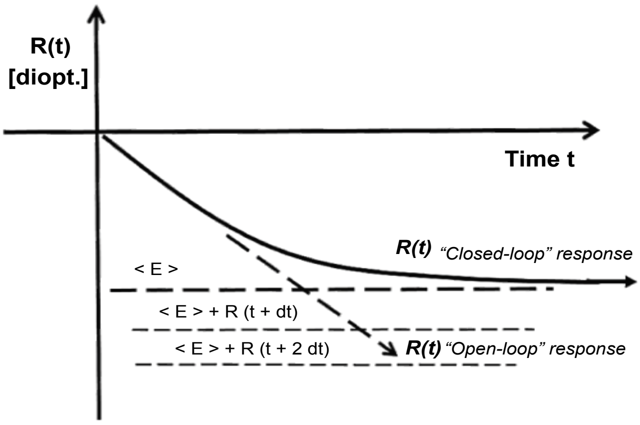


Figure A-1

Ordinarily, the 1st order closed-loop system response to a negative step $<E>$ is an exponential function with time constant τ . . .

Eq. A-1 $$R(t) = Ro + (Ro - <E>) \exp(-t/\tau)$$

(Closed-loop exponential response)

This is shown in Figure A-1 labelled as "R(t) closed-loop response". However, when the system demand function $<E>$ is continually increased in strength by each subsequent refraction R(t), moved lower and lower, as shown in Figure A-1, the applied load continually changes to $<E> + R(t)$. The basic differential equation governing these responses is . . .

Eq. A-2a $$dR(t)/dt = k[R(t) - <E>] = (1/\tau)[R(t) - <E>]$$ *(Closed-loop differential equation)*

(A-2b) $$dR(t)/dt = (1/\tau)[R(t) - (<E> + R(t))]$$ *(Open-loop differential equation)*

Note that the current refraction **R(t)** cancels out in (A-2b), and thus there is no feedback, basically an open-loop system.

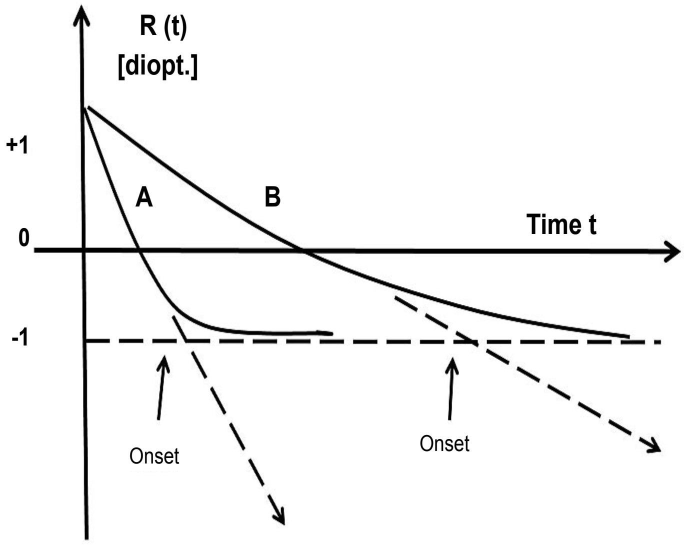
These equations are integrated, with Eq. (A-2a) resulting as Eq. (A-1) above and Eq. (A-2b) resulting in the observed linear ramp function

(A-3) $$R(t) = Ro - k <E> \times t = Ro - <E> (t/\tau)$$ *(Open-loop linear response)*

Where **Ro** is the initial refraction at time **to**, **$<E>$** is the average environmental near-point demand, **t** is time, and $\boldsymbol{\tau}$ is the system time constant.

Perhaps the most interesting feature of these results is that the system time constant $\boldsymbol{\tau}$ (typically $\tau = 0.25$ to 1.0 years) appears in both the closed-loop exponential and open-loop linear equations A-1 and A-3 above. In other words, the progressive myopia ramp-rate, Eq. A-3, is given by $R' = -<E>/\tau$, with units of [diopters/year], is *exactly the same* as the slope of the initial exponential emmetropization response, in diopters per year, given by Eq. A-1, as $R' = dR/dt = -<E>/\tau$ (typically R' = -0.5 to -1.0 diopters/year).

Conclusion: These results predict that those individuals with rapid emmetropization time constant $\boldsymbol{\tau}$ could also demonstrate rapid myopia rates **$<E>/\tau$** when continually corrected (Figure A-2).


R (t)
[diopt.]
+1
A
B
0
Time t
-1
Onset
Onset