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Short Communication

Progressive Myopia Dynamics. Analog Computer Model of Refraction Development

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- Refraction
- Bifocals
- Progressive add lenses

Abstract

Purpose: An AC – DC series electrical circuit is developed to simulate myopia progression R = R(t) [diopters], as the accumulated negative voltage at the series capacitor, with voltage Vc = V(t) [volts] representing the refractive error R(t) [diopters].

Methods: This circuit is an analogue computer which automatically solves 1st order system response equations for refractive status progression as a function of time, R(t). The new system voltage level is approached exponentially, typically with a time constant τ = RC = 60 to 100 days.

Results: This analogue computer technique is a general result, and can incorporate any combination of initial refraction R(0), refractive correction R1, and daily near-point demand - dR(t) to the visual system. As an example, the initial conditions for the subject's myopia are specified at Vc = - 5.0 volts DC [R(0) = - 5.00D], with an applied negative square-wave varying from 0 to -3.0 volts AC, representing a typical daily accommodative near work demand.

Conclusions: In terms of practical applications, positive +Add reading glasses, bifocals, and progressive addition lenses (PALs) have the effect of optically neutralizing the near-point environmental demands, stabilizing the negative system drift towards progressive myopia.

ABBREVIATIONS

R(t): Refractive Error [diopters] as a function of time; t: time [years]; R(0): Initial Refraction at t = 0; E(t): environment near-point reading demand [0 to -3 diopters]; τ: System Time Constant [60 to 100 days]; V(t): Voltage as a Function of Time; PAL = Progressive Addition Reading Glasses [+2 to +3 diopters]; D: Diopters: [1 / meters]; C: Capacitance [micro-Farads]; R: resistance [kilo-Ohms]

INTRODUCTION

Although a well-defined and well-documented technical problem, progressive myopia continues to elude the best efforts of our researchers world-wide. In practical clinical terms, -0.75 to -1.0 diopter of myopia corresponds to 3-lines on the Snellen eye chart, typically the difference between 20/20 and 20/10, or the difference between 20/40 and 20/20. Figure 1 and 2 below schematically show the -4 diopter demand on the eye's focusing system caused by studying, typical of some college students, and the proposed optical solution to this problem, by counter-acting the near point environment with a compensating (+) 3 D lens.

The problem of human progressive myopia is an intriguing, as yet unsolved, multi-parameter mystery. Undoubtedly a part of the explanation is inherited factors, part is environmental, as evidenced by nearwork myopia [1,2]. At present, myopia affects 25% to 40% of the U.S. population, perhaps 50% to 70% of the S.E. Asia area. Fairly harmless at less than - 6 diopters, the more advanced cases, - 7 diopters and beyond, may encounter a variety of medical problems, including macular impairment, detached vitreous or retina, staphyloma in the optic nerve region, loss of best-corrected visual acuity to less than 20/200, glaucoma, and cataract later in life [2,3].

Literature review – Walline [4], Flitcroft [2], Schmid [3], and Viikari [1], present comprehensive reviews of the myopia literature, including various techniques for myopia prevention. Holden et al. [5], review experimental research efforts concerning the myopia problem, showing that the human myopia progression-rate can be reduced by 55% using various types of (+) add lenses, shown here in Figure 3. Goss [6], reviews the effects of lenses on myopia progression in children. Cheng et al. [7], review the use of (+) lenses on myopia progression, citing all of the latest available literature on the subject. Myopia control and prevention is of extreme interest in the military, especially

Figure 1 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.

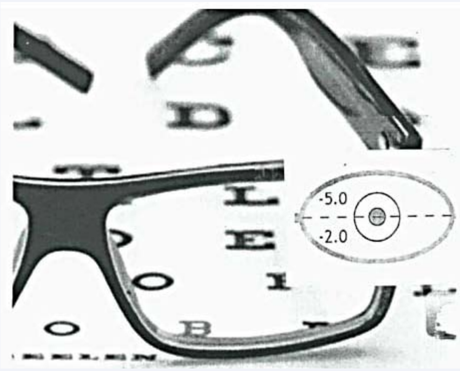

Figure 2 Reading glasses for a -5.00 D. college myope. (+) Add technology is used by both bifocals and progressive addition lenses, "PAL's". PAL's are "no-line" bifocals. Basically, these(+) Add reading glasses are distance compensators, with a +3.00 D Add for reading.

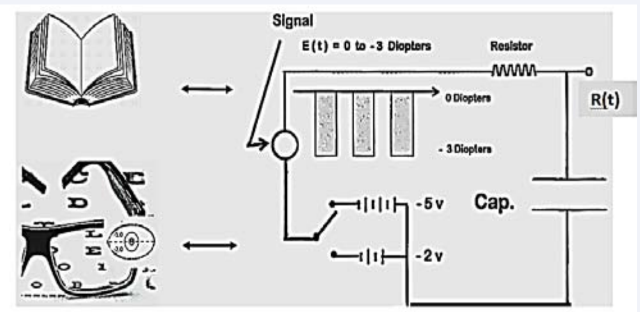

Figure 3 This schematic shows a - 5.00 diopter eye, with a + 3.00 diopter (decreased strength) lens used for a typical reading distance of 1 / 3 meter [14 inches].

for air force (USAF) and navy pilots (USNA), [8-12].

It should be pointed out that these various myopia prevention techniques do not always work as effectively as we might like. One of the main points of emphasis in this report, is that the eye's focusing control system seems to require a very special set of optical parameters, in terms of magnitude of correction (-2 to -3 diopters) and duration (equal to the total hours of study), in order to retain refraction stability over a long period of time (i.e. 4 to 8 years, typical of undergraduate and/or graduate work). In particular, it can be shown that the optical visual activity factor on the student's visual system is quantified as an *integral* of the number of "diopter-hours", the accumulated optical *"impulse"* demand. Evidently, without some sort of intervention procedure, the college student's visual system will drift further into myopia, typically at a rate of -0.3 to -0.5 diopters/year. It is fairly common to find a typical college myope, graduating 4 years later, with an additional -2 diopters of progressive myopia, often progressing from a nominal -4 diopters to -6, or even -5 to -7 diopters.

Recently, several (+) Add research studies have been published [13-18,7] with encouraging results, showing the progressive myopia-rate can be attenuated by 55% [5], using various (+) Add technologies, i.e. reading glasses, bifocals, or progressive addition lenses (PALs).

There are several reports of myopia developing with Navy submariners, and extensive LASIK use in the US Army [11] to cure the myopia problem, more than 16,000 recruits as of 2003, a total of 26,000 recruits as of 2005, a remarkably large study. The Annapolis Navy pilots at the United State Naval Academy (USNA) are required to be in excellent physical condition, it is a demanding job flying a Mach 2 fighter/bomber. These various (+) Add lenses can optically shift a book or computer at 13 to 20 inches to infinity, thereby reducing the stress on the accommodation system. Various types of reading glasses, i.e. single vision, bifocals, and the new multi-focal progressive lenses (PALs) may be a practical way to stabilize college myopia [19], and pilot myopia [8,9,12].

Nearwork has been proposed as a factor in myopia progression. Near work, such as intense computer work, can increase myopia [12]. Feedback Theory predicts a causative relationship between nearwork and myopia, as nearwork is equivalent to added minus (negative) lenses while looking in the distance. The effective nearwork distance, in diopters, is added as a step input demand-signal to the 1st order control system, which then responds by increasing the myopia.

The purpose of this report is to present a simplified solution technique to solve the differential equations that model progressive myopia. This model for refractive error development of the human eye requires that there is an optical return signal equal to the refractive error, which in turn corrects the refractive error of the eye. The first-order feedback system used here, defined by the transfer function **F(s) = 1 / (1+ks),** was proposed by Medina & Fariza [20].

MATERIALS AND METHODS

Acquired myopia equations

The human eye has a natural tendency to become myopic with long hours focusing at a near-point environment [21,19,10]. During the course of our college work, exploring reading glasses to stabilize myopia, the most difficult problem has been teaching and explaining the rationale of this optical technique [12]. Students grasp these ideas more readily, using differential equations and electrical engineering concepts, Figure 3 and Figure 4, show an analogue RC circuit simulating myopia progression vs. time R(t). The inset shows an applied negative square-wave representing the daily accommodative nearwork demand signal [20,22].

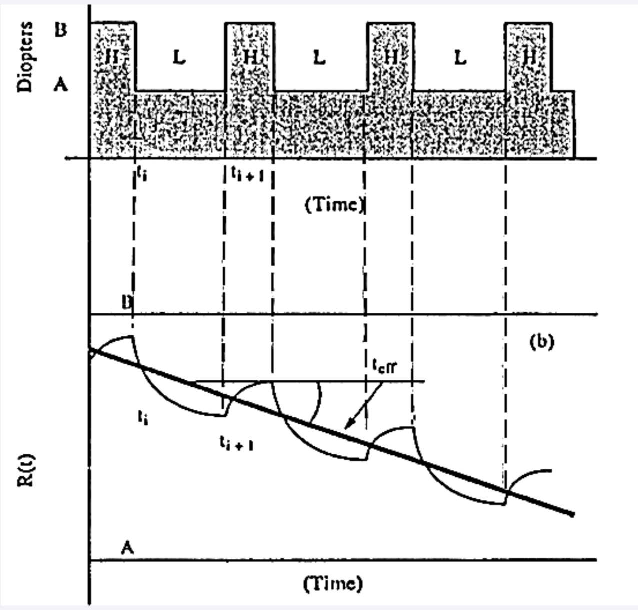

Figure 4 Visual system response R(t) [diopters] to the applied square wave E(t) = 0 to -3 D.

Equating Volts ~ Diopters, the system exhibits an exponential shift to more myopia [23,24], typically acquiring -0.3 to -0.4 D / year at college, with time constant τ = 60 to 100 days, usually in steps of - 0.5 diopters per year:

Equation 1: R (t) = - 5.00 D - 1.50 D x [1 – exp (- t / τ)] (DC = 0.5)

RESULTS

Analog-circuit solution

The electrical circuit, Figure 3, simulates myopia progression vs. time as the voltage at the capacitor, where Volts (v.) represent diopters (D). Initially, as a typical example, the subject's myopia is specified at - 5.00 D (V) and a negative square-wave varying from 0 to - 3.0 volts is applied, Figure 4, with variable duty-cycle (DC) intermittency factor [3] representing a daily accommodative nearwork demand (DC = 0.5) as the subject progresses from - 5.00 D to - 5.50 D. Medina [25], uses Laplace transform techniques solving 1-st order equations to calculate the drift of refractive status R(t).

Experimental details

Hobbyists with bread-board experience can easily build this analog circuit, using a digital voltmeter and frequency counter (Fluke DVM and Yaesu 500 MHz counter used here), analog voltmeter (Minolta from Radio Shack used here), or dual-beam oscilloscope (Tektronix 100 MHz and Hewlett Packard 60 MHz used here) comparing input and output voltages to monitor accumulated capacitor voltage Vc(t) proportional to the acquired myopia R(t). The square-wave is supplied with a low-frequency function generator (Wavetek 2-MHz and Heathkit 1-MHz used here) oscillating at 2-3 cycles/sec.

The economy oscillators only provide a 50% duty-cycle. One can scratch-build an astable multi-vibrator circuit [25], to provide a variable-intermittency variable duty-cycle square-wave. Some of the advanced "laboratory grade" oscillators include a DC-offset control, so the extra batteries in the Figure 3 circuit are already included. As a practical matter, we use a **C = 2,000 μF** capacitor, with an **R = 30 K Ω** resistor, having a time constant τ = RC = 60 s. = 1 min. Each day is accelerated or time-compressed to just 1-second, 2 months takes 1 minute, 1 year takes 6 minutes. Thus, 1-year, accelerated on the laboratory bench, corresponds to 6 time constants (**τ** = 60 d.) for the visual system. Because the circuit is symmetric with respect to (+) and (-) voltages, the conventional (-) polarity sign convention for concave lenses need not be installed. Conceptually, it is somewhat easier to assemble the circuit using (+) voltages for all components. Then, in order to display the negative going exponential sawtooth, it suffices to reverse the polarity of the oscilloscope probe.

DISCUSSION

Practical applications

The refraction response remains stable, R(t)=const., when using (+) Add lenses of strength +3.00 diopters, Figures 1, 2, 3 thus stabilizing the progressive myopia. This is because the battery switch, simulating reading glasses of one type or another, is synchronized with the square-wave input cycle, producing a null voltage, Figure 3. A practical clinical result is that different types of (+) reading glasses [5], have the capability to optically shift a book or computer screen from a typical reading distance of 1/3 meter (13 inches) to infinity, thereby reducing the focusing demand on the visual system.

CONCLUSIONS

This type of series electrical circuit is termed an accumulator or "integrator" circuit. Viewing myopia development in terms of this equivalent analog-circuit, the system responds to the applied square-wave cyclic load with a decaying sawtooth exponential, Figure 4, as can be demonstrated on an oscilloscope. This RC circuit is a minimum complexity single-parameter model, requiring only the subject's time constant τ. Circuits of this type demonstrate the required magnitude and duration of (+) lens use, necessary to counter-act a -3.0 diopter student work load.

Emmetropization

Medina et al. [19,20], find that the individual's emmetropization-rate and emmetropization time-constant determine the ensuing progressive myopia-rate. This means that an individual showing rapid emmetropization early in life, and then later becoming myopic, may also demonstrate rapid myopia-rates, indicating that an advanced case of progressive myopia can be predicted decades ahead of time. This "rate-equivalence" between emmetropization and myopia is consistent with the results presented here, indicating that progressive myopia is a matter of the recently corrected eye continually re-calibrating its parameters to achieve best possible focus, averaged throughout the day.

SUMMARY

Herein, a simple R-C series analog circuit is presented to solve the basic 1-st order myopia equations, showing how nearwork causes a myopizing progression, additional to that created by the constant value negative lens used to correct myopia. This analog-circuit technique is a general result, which as a practical matter, can account for many different variations of system parameters and initial conditions, including the patient's initial myopia (-5.00 D in this example), the nearwork load factor (50% intermittency in this example), the strength of reading glasses (+3D "Add" in this example) and the individual's emmetropization time-constant (60 days in this example). Each individual is different, so it is important to build this degree of flexibility into the circuit. In Figure 3, a -5 v battery is used to simulate -5 diopters of myopia, and a -3 v alternating square wave simulates the nearwork demand. The system response to reading glasses, a type of under-correction [26-28], is solved simply by replacing the -5 v battery with -2 v.

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