Optik 127 (2016) 896–899

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Mathematical models of college myopia

Peter R. Greene [a,*], Zachary W. Grill [b,1], Antonio Medina [c,2]

[a] B.G.K.T. Consulting Ltd., Bioengineering, Huntington, NY 11743, United States
[b] Temple University, Psychology, Philadelphia, PA 19122, United States
[c] Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, MA 02139, United States

ARTICLE INFO

Article history:
Received 5 February 2015
Accepted 29 October 2015

Keywords:
Progressive myopia
Feedback control theory
Progressive add lenses (PALs)
Bifocals
Reading glasses

ABSTRACT

Experimental design phase of a pilot study at Annapolis is described, using reading glasses, +1.5 D. to +3.0 D. to alleviate college myopia. College students often become 1.0–2.0 diopters more myopic, so reading glasses were explored to partially cancel the effects of the study environment. $N = 25$ different sets of (+)Add lenses are evaluated, for required adjustment period and reading comfort. Three computer models are developed to predict refraction versus time. Basic control system equations predict exponential myopia shift of refractive state $R(t)$. Linear, exponential and Gompertz computer results are compared calculating refraction $R(t)$ during the college years, showing correlation coefficients $|r| = 0.96–0.97$, accurate ± 0.31 D. over a 14 year interval. Typical college myopia rate is -0.3 to -0.4 D/yr. Reading glasses may be a simple, practical solution to stabilize college myopia.

1. Introduction

We helped design an experimental study at Annapolis, using reading glasses, to reduce college myopia. Navy pilots at Annapolis are required to have 20/20 vision in order to fly. Many become myopic and therefore must quit the program. Gmelin [1] reports that approximately 50% of Cadets start as myopic, but the fraction rises to two-thirds at graduation. In addition to the challenge of just getting the pilots to graduate, while still maintaining 20/20, we have received reports of a related phenomenon called "cockpit myopia", whereby, after close work at the instrument clusters, maps, instruction manuals, etc., the pilots and co-pilots find distance objects are blurred. In terms of motivation, some of the successful graduating Ensigns from Annapolis may, if they are lucky, go on to fly the new vertical take-off and landing F-35 VTOL, "Lightning II". It is difficult enough, trying to land on a pitching carrier deck, much more so if your vision is reduced to a 20/50 transient myopia during the sortie. Nearwork induced transient myopia (N.I.T.M.) is reported by some pilots, moreso the navigators, as expected. These various problems, although well defined, currently have no practical solution. Helmet display and optical design have become an integral part of aircraft design in recent years (Jenkins and Gallimore [2]). Our approach involved (+) Add reading glasses, +1.5 to +3.0 diopters, to be used during long hours of college study to lessen focusing effort (Cheng et al. [3]). In engineering terms, (+) Add reading glasses (Fig. 1), are considered "optical-offset distance compensators", designed to optically shift a book or computer at 13″–20″ to infinity, thereby easing the focusing work-load on the eye. Reading glasses may be a simple, practical, solution to stabilize college myopia and pilot myopia.

(+) Add studies require large numbers of students to improve significance level, discriminating the average diopter difference dR between experimental and control groups [14]. This difference is not always as pronounced as we might hope (Cheng et al. [3]). Fulk et al. [4] report $N = 42$, dR = 0.25 D, $p = 0.046$, using a +1.50 D. add. Gwiazda et al. [5] report $N > 450$, dR = 0.20 D, $p < 0.004$, using a +2.00 D. add. Yang et al., [6], using a +1.50 D. add, report N = 149 subjects, dR = 0.25 D, $p = 0.01$. Leung and Brown [7] report dR = 0.7 D., $p < 0.0001$, using = +1.50 D and +2.00 D, $N = 36$. Cheng et al. [3] report dR = 1.05 D., $N = 135$, using +1.5 D Add and +1.5D with prism, $p < 0.001$. Oakley and Young [8] report dR = 1.0 D, $N = 216$ (Fig. 2), using +1.5 D and +2.0 D Add, $p < 0.001$ for each of 10 different age brackets. Cheng et al. [9] and Goss [10] review the literature on (+) Add studies, including bifocal and multi-focal lenses.

* Corresponding author. Tel.: +1 631 935 56 66.
E-mail addresses: prgreeneBGKT@gmail.com (P.R. Greene), zacharywgrill@gmail.com (Z.W. Grill), medina_NASA@hotmail.com (A. Medina).
[1] Tel.: +1 516 864 96 15.
[2] Tel.: +1 714 418 11 83.

http://dx.doi.org/10.1016/j.ijleo.2015.10.190
0030-4026/

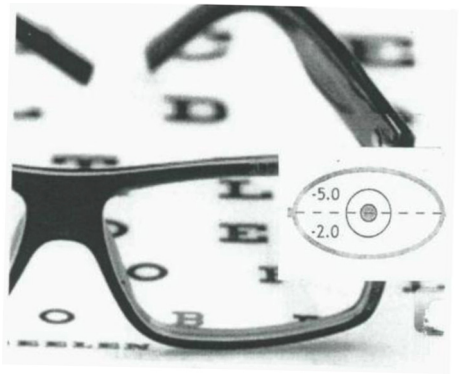

Fig. 1. Reading glasses for a −5.00 D. college myope. (+) Add technology is used by both bifocals and progressive addition lenses, "PAL's". PAL's are "no-line" bifocals. Basically, these (+) Add glasses are optical-offset distance compensators. Inset shows standard executive style bifocals with a +3.00 D Add for reading.

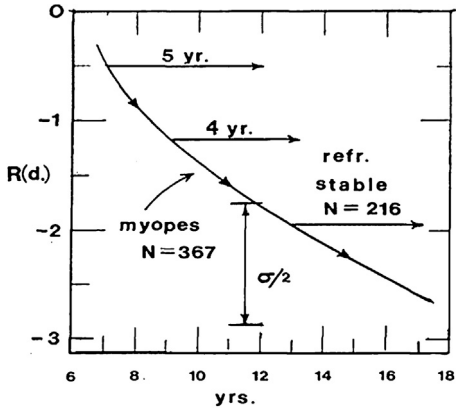

Fig. 2. +2.0 D bifocals ($N = 216$) can stabilize progressing myopes ($N = 367$), as indicated by the horizontal lines. dR = 1.0 D., $p < 0.001$ for each of 10 age brackets. Otherwise, normal myopia refraction rates are $R'(t = 8\ \text{yrs}) = -0.7$ D/yr, $R'(t = 16\ \text{yrs}) = -0.4$ D/yr. Exponential myopia time constant is $t^* = 3.2$ years.

2. Materials and methods

The design team consisted of 5 consultants, from various universities, ages 30–60, plus 2 assistants ages 21–30 yrs. Comfort level, feasibility, and endurance factors were evaluated for the 25 different (+) Add lens combinations (Table 1). In terms of mathematical theory, 3 computer models of refractive-state shift over an 11–14 year interval are developed, including *linear* (Goss and Jackson [11]; Medina et al. [12a,b]), *exponential* (Medina and Fariza [12]), and *Gompertz* (Thorn et al. [13]). Age matched data sets (Figs. 2 and 5), are used to optimize model parameters. Results are calculated using Basic V. 3.2 and Excel programs. Cheng et al. [3] and Goss [10] review plus lenses, bifocal, and PAL studies. Typical college myopia rate is $R' = -0.3$ to -0.4 D/yr. Our objective was to reduce the rate to 0.0 D/yr for 4 years. These myopia rates are typical (Lee et al. [14]; Sun et al. [15]; Lin et al. [16]; Yang et al. [6]) and also apply to students at the graduate level, some medical schools reporting myopia prevalence rates greater than 90–95% (Lin et al. [16]). Recently, several (+) Add research studies have been published (Gwiazda et al. [5]; Leung and Brown, [7]; Fulk et al. [4]; Oakley and Young [8]; Yang et al. [6]; the COMET Group [17]; Cheng et al. [3,9]) with encouraging results, i.e. the progressive myopia rate can be attenuated by 50% or more (Holden et al. [18]) using various (+) Add technologies, i.e. bifocals and progressive addition lenses (P.A.L.'s) (Fig. 2). Under proper supervision, we evaluated an assortment of (+) Add lenses, with powers ranging from +0.5 D. to +4.0 D. (Table 1). Tenets of the Helsinki declaration and the internal review board were adhered to. Comfort level for these reading glasses was such that they are still in use by most members of the design team.

Table 1

(+) Add [D]		Adapt. time	Duration	# subj.	Cost
1.	+0.5	<1 h	2 yrs.	1	$200
2.	+1.0	2 h	2 yrs.	1	$200
	+1.0	2 h	0.5 yr.	1	$250
3.	+1.5 clip-on lenses	3 h.	n.a.	3	$12
	+1.5	3 h.	2 yrs.	1	$200
	bifocal sunglasses	<1 h	n.a.	2	$16
		<1 h	1 wk.	1	$250
4.	+2.0	1 day	20 yrs.	2	$200
		1 day	1 wk.	1	$250
5.	+ 2.5 clip-on lenses	1 day	n.a.	3	$12
6.	+ 3.0	1 wk.	1 yr.	1	$200
		1 wk.	1 wk.	1	$250
7.	+3.25	n.a.	n.a.	2	$12
8.	+3.5	1 m.	1 yr.	1	$200
		1 m.	1 m.	1	$250
		1 m.	1 m.	1	$250
9.	+4.0	2 m.	1 yr.	1	$200
"flipper" lenses −2.0 to +2.0 D		0	1 h	1	$25

3. Results

Mathematical models of progressive myopia involve exponential and/or linear functions. The refractive state as a function of time, $R(t)$ [diopt], of the eye responds, re-adjusting to the near-point optical demands of a new environment ⟨E⟩ [diopt.], typically ⟨E⟩ = −1 to −2 D. During one semester, refractive state can become negative, about −0.3 diopters, with a time constant $t_0 = 60$–100 days as:

$$R(t) = -1.1D + 0.8D * \exp\left[\frac{-t}{t_0}\right] \quad (1)$$

Similar exponential functions are used by Medina and Fariza [12] and Greene et al. [19,19a].

In terms of theory, we have explored 3 possibilities in detail: (1) linear regression (Goss and Jackson [11]) ($N = 12$); (2) exponential progression ($N = 367$) (Medina and Fariza [12]) and (3) the Gompertz function (Thorn et al. [13]), $N = 32$ iterations. The Gompertz 4-parameter double-exponent is given by:

$$R(t) = Re + Rc * (0.07295)\ \hat{}\ [a\ \hat{}\ (t - t_0)] \quad (2)$$

where $R(t)$ = refraction at time t. For one subject, we use parameters $Re = -0.75$ D initial refraction, $Rc = -5.25$ D amplitude, onset age $t_0 = 12$ yrs., and $a = 0.70$ optimal shape factor, accurate within ± 0.31 diopters. The results for *linear regression* show average diopter rate $\langle R' \rangle = -0.47$ D/yr., age at stabilization 22 years, correlation coefficient $r = -0.96$. For the *exponential model* time constant is $t^* = 3.2$–4.4 yrs., correlation coefficient $r = 0.97$, accurate over an 11–14 year interval (Figs. 2, 4 and 5). Mathematically, the *regression model* is the easiest to use, the *Gompertz model* is the most difficult, but most accurate, and the *exponential model*, of intermediate difficulty (Figs. 2, 4 and 5), has the ability to predict the slower myopia drift after college (for instance, Fledelius [20] reports that an additional 25% of the students become myopic during graduate school).

3.1. Design team data

From the $N = 7$ consultants on the design team, 5 are myopes with nominal spherical equivalent refraction (SER) from −5 to −8 D., two are emmetropes. 4 of the myopes try and like reading glasses, using various types of (+) Add lenses for an extended period of time. Myopia can continue to progress beyond the college years to age 40–45, rarely mentioned in reports (Bullimore et al. [21];