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An application of threshold-versus-intensity functions in automated static perimetry

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Abstract

Increment thresholds were measured over a range of adapting illuminances using a modified automated static perimeter. The data were fitted to a threshold versus intensity model ($\log T = \log T_0 + \log((A + A_0)/A_0)^n$) and the values $\log T_0$ and $\log A_0$ estimated. The effect of eccentricity and age on $\log T_0$ and $\log A_0$ was examined in normal subjects. A small group of patients with ocular disease were then assessed. Macular degeneration appeared to act as disease processes acting near the photoreceptor (d1 model). Glaucoma seemed to act near the site of retinal gain (d3 model). This analysis method may be of value in developing light adaptation strategies in people with ocular disease.

Keywords: tvi; Light adaptation; Perimetry

1. Introduction

Perimeters are a basic clinical tool used to detect areas of reduced sensitivity in the visual field. As the sensitivity values measured by perimeters change with the background illumination level, perimeters have a set bowl luminance. Commonly used background luminance levels range from 10 cd/m^2 in the Humphrey field analyser (HFA) to 1.3 cd/m^2 in the Octopus perimeter. Yet the visual environment is a place full of different light levels. Could more information be gained through performing perimetry using a range of background luminance levels? This question has been an area of research in perimetry for many years. Testing at lower and higher background luminance levels has been proposed (Bedwell & Obstfeld, 1972; Frankhauser, 1979; Greve, 1980; Owsley et al., 2000; Paige, 1985; Starita, Fellman, & Lynn, 1987; Vingrys & Demirel, 1998).

However practical concerns, comparison difficulties and threshold fluctuations have minimized the use of non-standard adaptation levels (Heijl, 1985; Henson, 1993).

The threshold-versus-intensity (tvi) function has been used to study the increase in increment threshold with increasing background luminance for many years (Aguilar & Stiles, 1954). An extensive literature has developed examining the tvi function in normal observers (Hood & Finkelstein, 1986), infants (Brown, 1986; Hansen, Fulton, & Harris, 1986) and patients with retinal disease (Greenstein, Holopigian, Hood, Seiple, & Carr, 2000; Greenstein, Shapiro, Zaidi, & Hood, 1992; Holopigian, Seiple, Greenstein, Hood, & Carr, 2001; Hood & Greenstein, 1988; Hood et al., 1998; Hood & Zhang, 2000; Seiple, Holopigian, Greenstein, & Hood, 1993; Young, Price, & Harrison, 1986). A model linking much of the tvi literature was proposed by Hood and Greenstein (1990). The basic premise of the model is that adaptation to a background illuminance can be described by a two site model, where site 1 is the photoreceptor and site 2 is a post-receptoral system containing

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a gain altering adaptation mechanism. The shape of the tvi function can be modeled using Eq. (1)

$$\log T = \log T_0 + \log((A + A_0)/A_0)^n, \quad (1)$$

where T is the threshold, T_0 is the unadapted threshold illuminance specifying the vertical position of the function, A is the adapting illuminance, A_0 specifies the horizontal position of the function and n is the slope of the function. If the data are fit to this equation then estimates of $\log T_0$ and $\log A_0$ can be obtained. These variables define the visual adaptation function and can be used to determine the locus of a particular disease process. Disease can act either at the photoreceptor level (d1) or in the post-receptoral system (d3). If the disease process acts at the d1 locus then there would be a reduction in quantal catch due to a loss of photopigment, damage to the photoreceptor or a decrease in incident light from a pre-retinal filter (Hood & Greenstein, 1990; Seiple et al., 2002). The result would be an identical multiplicative increase in both $\log T_0$ and $\log A_0$. If the disease process acts at the d3 locus then the effect would be seen as an increase in $\log T_0$ only. Again; the reader is referred to Hood and Greenstein (1990) for a more complete explanation of the model and its application to assessing ocular disease.

Two studies have attempted to apply tvi analysis directly to visual field loss as measured on a static perimeter (Hood & Zhang, 2000; Seiple et al., 2002). Unfortunately, little direct correlation was found between the results obtained from the two different methods. It was speculated that the multifocal ERG stimuli used may have been too large and diffuse to produce the well-defined retinal simulation produced by a static perimeters (Hood & Zhang, 2000). The current study will address this possibility by using a modified static perimeter to measure increment thresholds over a range of background adapting illuminances. These data will then be analysed using a tvi approach proposed by Seiple, Greenstein, Holopigian, Carr, and Hood (2002) and finally compared to a standard HFA result.

2. Methods

2.1. Subjects

2.1.1. Controls

Twenty subjects (10 female) were recruited from the Optometry Clinic of the School of Optometry and Vision Science, University of New South Wales. Subjects were aged between 20 and 65 years of age (mean 43 years), had a best correct visual acuity of at least 20/20 and no known history of eye disease or cataract. All subjects were experienced in performing automated perimetry and underwent a routine ocular examination. Institutional approval was obtained and the tenets of the Declaration of Helsinki were followed. Informed consent was obtained from all subjects.

2.1.2. Ocular disease

Four male subjects were recruited from the Optometry Clinic of the School of Optometry and Vision Science, University of New South Wales. Subjects were aged between 65 and 79 years of age (mean 73 years) and had a best correct visual acuity of at least 20/30. All subjects had long-standing diagnoses and were under routine ophthalmological care. All subjects were experienced in performing automated perimetry. The characteristics of the ocular disease subjects are given in Table 1. Institutional approval was obtained and the tenets of the Declaration of Helsinki were followed. Informed consent was obtained from all subjects.

2.2. Perimeter

The M600 automated static perimeter (Medmont, Camberwell, Australia) was used. The M600 is made of a separate stimulus bowl connected to a standard personal computer. The bowl is lit by a ring of tungsten light sources placed near the front rim of the bowl. The standard bowl luminance of 3.2 cd/m^2 is intermediate between that of the HFA and the Octopus perimeter.

Table 1
Characteristics of subjects with ocular disease

Diagnosis	Age	Visual acuity	MD (dB)	PSD (dB)	Abnormal points in HFA plot	Increase in $\log T_0$ at HFA illuminance	Abnormal points using tvi analysis
AMD	79	20/30	+0.53	1.38	0/52 = 0%	0.44	16/30 = 53%
AMD	75	20/30	−4.46	2.50	12/52 = 23%	0.08	30/30 = 100%
POAG	73	20/25	−6.21	3.24	41/52 = 79%	0.94	26/30 = 87%
POAG	65	20/20	−1.42	2.41	7/52 = 13%	0.58	19/30 = 63%

The diseases assessed were age-related macular degeneration (AMD) and primary open angle glaucoma (POAG). MD represents the mean depression reported on the Humphrey Field Analyser SITA standard 24/2 Central Threshold test. The value is in decibels of stimulus attenuation (dB). PSD represents the Pattern Standard Deviation in dB. The abnormal points in the HFA are the sum of points shown on the Total Deviation STATPAC result having a probability of less than 2%. The column Increase in $\log T_0$ gives the increase in $\log T_0$ at an adapting illuminance of 1.85 log troland (equivalent to that of the HFA). The column Abnormal points in tvi analysis gives the sum of those points having a $\log T_0$ lying outside the calculated 99% confidence interval for that particular visual field test location. See the text for further clarification of these data.