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Response times across the visual field: Empirical observations and application to threshold determination

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ABSTRACT

This study aimed to determine if response times gathered during perimetry can be exploited within a thresholding algorithm to improve the speed and accuracy of the test. Frequency of seeing (FoS) curves were measured at 24 locations across the central 30° of the visual field of 10 subjects using a Method of Constant Stimuli, with response times recorded for each presentation. Spatial locations were interleaved, and built up over multiple 5-min blocks, in order to mimic the attentional conditions of clinical perimetry. FoS curves were fitted to each participant's data for each location, and response times derived as a function of distance-from-threshold normalised to the slope of each FoS curve. This data was then used to derive a function for the probability of observing response times given the distance-from-threshold, and to seed simulations of a new test procedure (BURTO) that exploited the probability function for stimulus placement. Test time and error were then simulated for patients with various false response rates. When compared with a ZEST algorithm, simulations revealed that BURTO was about one presentation per location faster than ZEST, on average, while sacrificing less precision and bias in threshold estimates than simply terminating the ZEST earlier. Despite response times varying considerably for a given individual and their thresholds, response times can be exploited to reduce the number of presentations required in a visual field test without loss of accuracy.

1. Introduction

Measuring visual function across the visual field has well documented difficulties imposed by the desire to test many individual spatial locations within the constraints of tolerable test durations. In particular, current commercially available visual field testing algorithms suffer from high test–retest variability in areas of visual field loss (Artes et al., 2002; Turpin et al., 2003). Given the small number of stimulus presentations at each spatial location, it would be advantageous to exploit all available information from each stimulus presentation and subject response to improve the test.

Response times are one example of information collected during visual field testing that could potentially be used to inform the testing algorithm. At present, response times are used in several commercial perimeters to determine whether a response is likely to be a genuine response to a stimulus, or a false positive (Bengtsson et al., 1997; Olsson et al., 1997). Since some people simply respond faster on average than others, response times are also used in some perimetric algorithms to adjust the window between stimuli (Bengtsson et al., 1997). This enables faster responders to have a shorter response window, thereby reducing test duration. A commonly used procedure that has adopted these approaches is the Swedish Interactive Threshold Algorithm (SITA) (Bengtsson et al., 1997; Olsson et al., 1997).

There is a wealth of literature in a range of behavioural disciplines that demonstrates that response times vary according to a range of factors intrinsic to the observer (such as cognitive capacity, Hultsch, MacDonald, & Dixon, 2002) that interact with experimental parameters such as the probability of stimulus occurrence and its salience (for review see Schall & Bichot, 1998). A key factor in visual field testing is the visibility of the stimulus, with response times being quicker on average for stimuli that are highly visible than for those close to threshold (Bartlett & Macleod, 1954; Wall, Kutzko, & Chauhan, 2002; Wall et al., 1996). Consequently, response times may provide information regarding the relative visibility of the stimulus within a perimetric test. However, as response times to a particular stimulus show considerable intra- and inter-observer variability, the magnitude of benefit that such an approach might yield is not immediately obvious. It is not possible to use response times collected directly from commercial perimeters to explore this issue as an

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understanding of how response times relate to the probability of seeing the presented stimulus is required.

Wall et al. recorded response time measures in conjunction with the collection of frequency of seeing data (psychometric functions) for perimetric stimuli (Wall, Kutzko, & Chauhan, 2002; Wall et al., 1996). In their first study (Wall et al., 1996) the authors measured frequency of seeing curves in two visual field locations, with a total of 205 presentations at each location. A further eight randomly chosen locations were also tested with three repetitions of a highly visible 0 dB stimulus (i.e. 24 extra trials). Hence 95% of presentations occurred at two visual field locations only. Their second study was designed to explore the effect of visual field eccentricity on response times (Wall, Kutzko, & Chauhan, 2002). Ten visually normal experienced observers were tested from 10° to 50° eccentricity along the horizontal meridian in 10° increments. Each location was tested 460 times with locations being interleaved within a single two-hour test session. The analysis concentrated on the difference in response times at threshold (determined as the 50% probability of seeing point on the frequency of seeing curve) to that of a highly suprathreshold stimulus (0 dB).

These previous studies provide data on the relationship between response times, visual field eccentricity and visual field sensitivity, however, the experimental designs did not truly mimic the attentional demand or duration of a perimetric test. Response times are slower when attention is divided across spatial locations (Mangun & Buck, 1998), and the probability of stimulus occurrence at any given spatial location also influences response time (Anderson & Carpenter, 2006). The purpose of our study was to measure observer response times during the collection of frequency of seeing (FoS) curves, and then to use those measures to determine whether Bayesian algorithms for perimetry can be improved by response time information. Our collection of empirical response times employed methods designed to more closely mimic perimetric testing conditions than previous studies (Wall, Kutzko, & Chauhan, 2002; Wall et al., 1996). FoS curves were measured in an interleaved fashion at 24 spatial locations built up via multiple 5–6 min perimetric tests. We aimed to determine how response time relates to an individualised "distance from threshold" measure that is based on the psychometric slope for a given location and observer. We then used this empirical data and computer simulation to explore the potential benefits and trade-offs of incorporating response time information into a Bayesian adaptive thresholding algorithm for perimetry (BURTO: Bayesian Updating with Reaction Time Offset). Our simulations demonstrate a new way to use response time information to shorten perimetric tests, without compromising accuracy or precision.

2. Methods

2.1. Participants

Ten adults with normal vision (aged 21–41 years) participated. Note: because we determine how response time relates to an individualised "distance from threshold" based on the psychometric slope, the data can be used to model observers with visual field loss. Previous research demonstrates that the response times to stimuli presented at threshold (50% probability of seeing) do not differ between normals and those with glaucoma, even in areas of visual field loss (Wall et al., 1996). All had best corrected vision of 6/6 or better, refractive error within ±5*D* of sphere and 2*D* of cylinder, and normal ocular health as determined by a routine clinical eye examination. All were perimetrically experienced observers. Prior to participation, all participants provided written informed consent in accordance with a protocol approved by the Human Research Ethics Committee of The University of Melbourne, and the Declaration of Helsinki. Participants attended 5–6 test sessions, each of approximately 45 min duration, over a 2–4 week period.

2.2. Equipment

Stimuli were presented on a gamma-corrected 21-in. monitor (G520 Trinitron, Sony, Tokyo, Japan: maximum luminance: 100 cd/m^2; frame rate: 100 Hz; resolution: 1024×768 pixels) using a ViSaGe system (Cambridge Research Systems, Kent, UK) interfaced with a desktop computer. Software was custom written in Matlab 7.0 (Mathworks, Natick, MA, USA). Participant responses were collected with a CB6 response box (Cambridge Research Systems) which sends an infra-red (IR) trigger to an IR receiver on the ViSaGe. The ViSaGe accesses the PC hardware independently hence controls timing separately to any background processing by Windows. The CB6 returns response times to a nominal precision of 0.1 ms. Participants sat 40 cm from the screen, wearing appropriate refractive correction for this distance, with chin stabilized using a chinrest. Testing was performed monocularly. Measures were made for one randomly selected eye of each participant. A central fixation marker (0.25° black square) was present during inter-stimulus intervals and prior to test commencement.

2.3. Testing strategy

The stimulus (0.43° circular luminance increment, Goldmann size III), duration (200 ms) and background luminance (10 cd/m^2) were chosen to match those typical of clinical static automated perimetry (for example, the Humphrey Field Analyser, Carl Zeiss Meditec, Dublin, CA, USA). FoS curves were measured at 24 locations across the visual field (Fig. 1), using a Method of Constant Stimuli (MOCS) procedure. Each psychometric function was measured with 7 contrast steps. The contrast steps were determined by initial pilot testing in each observer and were expressed in units of whole dB, with luminance levels being equivalent to the dB scale on the Humphrey Field Analyzer (cd/m^2 = $10^{4-\mathrm{db}/10}/\pi$). The testing of locations was interleaved, with each of the seven steps for a given location presented once within a visual field test run. In other words, one test run included 24 locations $\times$ 7 contrast steps for a total of 168 presentations. An additional 14 blank presentations where no stimulus was presented were interleaved at random within the test to collect false positive responses. This total of 182 presentations created a visual field test of approximately 5–6 min duration. Participants were instructed to maintain central fixation and to press the button whenever a stimulus was seen within their visual field. Response times were measured as the time between the beginning of the stimulus presentation and the participants button response (CB6, Cambridge Research Systems, Kent, UK). A maximum response window of 1500 ms was allowed, and if the participant did not respond during that period, the stimulus was "not seen".

In order to build up the psychometric functions, visual field tests were run 30 times. The 30 visual field tests were collected over the 5–6 test sessions.

2.4. Analysis of empirical data

FoS curves for each participant at each location were modelled as Cumulative Gaussian functions (Fig. 2), and fit using a non-linear least-squares approach (nlm function in R version 2.15.2 (R Development Core Team, 2012). Threshold was defined as the mean of the cumulative Gaussian fit (50% probability of seeing). The spread of the psychometric function was determined as the standard deviation of the Cumulative Gaussian, where a smaller standard deviation represents a steeper psychometric function (Fig. 2).