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Effects of Retinal Image Degradation on Pre-Attentive Visual Search (PAVS) Efficiency for Flicker, Movment and Orientation Stimuli

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Effects of retinal image degradation on pre-attentive visual search (PAVS) efficiency for flicker, movement and orientation stimuli

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Abstract

Background: Previous research has shown that several clinical conditions cause increased pre-attentive visual search (PAVS) times, implying reduced parallel search capabilities in glaucoma and DLB dementia. The purpose of the research reported here was to examine for the first time the resistance of PAVS to dioptric blur using targets differing from the background in terms of flicker, vertical displacement, and orientation. Resistance would enhance the applicability of PAVS as a screening method for glaucoma and other clinical conditions affecting performance of a substantial area of the retina.

Method: Computer generated flicker, orientation and vertical displacement targets were used to assess PAVS efficiency. The subject's task was to locate a small single target subtending 0.92° as quickly as possible (embedded in a field of 119 distractors) on either the left- or right-hand side of a computer monitor. Average PAVS response times were calculated for 40 presentations of each target type presented randomly in any one of 120 positions within ±15° of fixation. Subjects performed the test using their distance spectacles (unless emmetropic), then three tests using positive lenses simulating myopia of up to −3 D, and finally using optimum correction again.

Results: ANOVA revealed that blur of up to 3 D had no statistically significant effect on response times to the *flicker* target. Blur of over 2.0 D however resulted in increased response times for the *oscillation* target, but only for eyes, which were not cyclopleged. The *orientation* target became significantly more difficult to locate, response times becoming progressively slower with increasing levels of blur ($p < 0.05\%$).

Conclusions: The present flicker and displacement targets are relatively resistant to the effects of reduced acuity, while the orientation target is only suitable for testing subjects with good visual acuity.

Keywords: blur, displacement, flicker, orientation, pre-attentive visual search

Introduction

Pre-attentive vision implies parallel processing by the visual system on multiple target features simultaneously (Treisman, 1985; Townsend, 1990). Several studies have shown that the search for a target pattern among distractor (non-target) patterns is fast and parallel once this target differs significantly from its background in some basic stimulus dimension (Nakayama and Silverman, 1986; Nothdurft, 1991, 1993; Saarinen, 1996). A pre-attentively detected stimulus appears to 'pop-out' (Saarinen, 1996) and this pop-out allows very rapid detection of a target among a field of distractors before a saccadic eye movement can be made.

Pre-attentive vision is therefore a global visual function that can perform a simple analysis of image content simultaneously across an entire image, whereas only a single area can be analysed by serial mechanisms at any

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one time. Consequently, it is a reasonable assumption that PAVS is dependent on neural mechanisms being intact across the retina, not just at the fovea. If this is the case, a suitably configured PAVS test might be able to detect any retinal disease or other condition that produces damage across a significant area of the visual field, as distinct from a condition producing foveal/macular damage only. We assume that mean visual search times of between 0.4 and 0.7 s without blur in the present study in the presence of 119 distractors indicates that search is pre-attentive for the tests used here: see Appendix.

PAVS in glaucoma and other clinical conditions

The pop-out phenomenon is a psychological process involving the involuntary jerking of attention to an odd item (Nakayama, 1999). The fast and efficient processing of such highly important information probably evolved as an early warning survival mechanism and is most likely coded (for movement perception at least) by the more transient and fast-conducting magnocellular pathway (Livingstone and Hubel, 1987; Merigan *et al*., 1991).

Glaucoma is an optic neuropathy normally resulting in irreversible damage to ganglion nerve cell axons. There is evidence to suggest that large diameter axons are preferentially damaged in early glaucoma (Quigley, 1987; Quigley *et al*., 1988; Anderson and O'Brien, 1997). It has also been shown that at any particular retinal location, magnocellular cells tend to have larger axon diameters than do their parvocellular counterparts (Quigley *et al*., 1988). Any preferential damage to this pathway may result in compromised search efficiency, particularly in light of the retinal under-sampling and therefore reduced redundancy of these axons.

It is possible that a PAVS test with suitable stimulus parameters (the current test presents a flicker and displacement target modulated at 16 Hz to preferentially stimulate the magno-pathway) provides an efficient way of monitoring the status of the magnosystem. If pop-out does not occur, for example, because glaucoma is present, search will be more serial in nature and response times will increase accordingly.

Recently, several studies have looked at potential applications of the PAVS technique to detection and diagnosis of clinical conditions, including glaucoma (Flitcroft *et al*., 1996), Parkinson's disease (Troscianko and Calvert, 1993) and dementia (Cormack *et al*., 2004). In the former case, the authors reported that the three tests in their battery of PAVS tests successfully discriminated between patients with and without glaucoma. The same targets were used in the present study. The reason for using these paradigms in the present study is two-fold. Firstly, flicker and oscillation targets (as used by Flitcroft *et al*., 1996) have been shown to be sensitive to glaucoma in a conventional single target psychophysical (non- visual search) environment (Tyler, 1981, Fitzke *et al*., 1987). The PAVS response time paradigm as used here has potential advantages over flicker perimetry in terms of speed and being easily understood by patients.

Second, we wished to see whether Flitcroft *et al*.'s findings for PAVS in glaucoma could be substantiated using the same paradigms; this is the subject of a separate study by the present authors.

Other clinical studies using PAVS include Troscianko and Calvert (1993) who found that pop-out using a bar-shaped target differing in orientation from its distractors was impaired in Parkinson's disease. In Cormack *et al*.'s (2004) study, the task was to detect a red target embedded in green distractors. While PAVS was found to correlate with DLB dementia, complex reaction time showed no correlation.

To date little attention has been paid to the potentially complicating effects of retinal image degradation on search performance. Thus false positive results could conceivably be expected if a PAVS test, used for screening purposes, is too sensitive to dioptric blur simply because a patient is not wearing an optical correction when taking a PAVS test. Screening for glaucoma and other conditions must sometimes be performed in circumstances where visual acuity is reduced for purely optical (defocus) reasons.

The purpose of the research reported here was to examine the resistance of PAVS to dioptric blur using targets differing from the background in terms of flicker, displacement, and orientation since to our knowledge this has not been previously examined. We might expect the former two conditions to show some resistance to defocus, based on findings with conventional psychophysical targets (flicker: Lachenmayr and Gleissner, 1992; displacement: Whitaker and Buckingham, 1987). Similarly, we might expect the orientation target, being essentially an acuity target, to show a predictable lack of resistance. However, the nature of PAVS tasks is clearly very different from conventional psychophysical tests. The purpose of the present study was to examine whether similar effects occur for PAVS tasks. Resistance to dioptric blur would enhance the applicability of PAVS testing to glaucoma and other clinical conditions affecting performance of a substantial area of the retina, while lack of resistance would increase the incidence of false positives if PAVS were to be used for clinical screening.

In this paper, we have deliberately chosen PAVS stimuli for which the difference between target and distractors is high as a supra-threshold environment is generally more effective for visual screening purposes, for example in testing of visual fields (Henson and

Agnihotri, 1995). The use of a response time here, rather than threshold experimental paradigm, also simplifies the nature of the PAVS test from the subject's point of view. This has potential advantages if the test is to be applied to patients with a limited span of attention, including elderly patients amongst whom most types of glaucoma are most prevalent (e.g. Klein *et al*., 1992).

Method

Subjects

A total of 17 adults ranging from 16 to 22 years (mean = 18 years) were tested, all being normal according to the following criteria: no history of treatment for or family history of glaucoma, normal optic nerve and retinal nerve fibre layer (assessed by direct ophthalmoscopy), wide open anterior chamber angle (van Herick's technique, using a slitlamp biomicroscope), and intraocular pressure < 21 mm Hg. (mean of three readings with the Pulsair non-contact tonometer). All subjects were judged to be free from glaucoma and hypertension on this basis; these are necessary exclusions since Flitcroft *et al*. (1996) have shown PAVS to be affected by both conditions. All subjects achieved logMAR 0 (6/6) or better visual acuity on a Bailey–Lovie test chart.

Apparatus and stimuli

The visual search test was presented on a 19-inch Iiyama colour monitor (Vision Master^{TM} 450, model S901GT: Iiyama UK Ltd., Stevenage, Herts, UK) with 640 × 480 resolution at 80 Hz refresh rate and dot pitch of 0.26 mm. The test area subtended 33.8° horizontally and 25.8° vertically at a fixation distance of 50 cm. The white targets and distractors subtended 0.92° with a 1.83° gap between stimuli. Neither targets nor distractors were presented within the blind spot. The software used to present and control the experiment was adapted from that used by Flitcroft *et al*. (1996); it was written in ANSI C and run on a Pentium 1 PC running at 100 MHz. *Figure 1* shows a diagrammatic representation of the target and 119 distractors as presented for the orientation test.

Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z	Z
Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z	Z
Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z	Z
Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z	Z
Z	Z	Z	Z	Z	Z	×	Z	Z	Z	Z	Z	Z
Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z	Z
Z	Z	Z	Z	Z	Z		Z	Z	Z	N	Z	Z
Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z	Z
Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z	Z
Z	Z	Z	Z	Z	Z		Z	Z	Z	Z	Z	Z

Figure 1. Diagrammatic representation of test pattern for the PAVS orientation test. Subjects were required to fixate the central cross and to detect the target (N) among the distractors (Z).

Targets were white with mean luminance of 132 cd m^{-2}; mean background luminance was 2 cd m^{-2} giving a Michelson contrast ratio of 0.97. The flicker target was a white filled square box of the above dimensions, square-wave modulated at 16 Hz, and surrounded by identical non-flickering boxes as the distractors. The displacement target was an empty white box (white lines of width 1 mm, subtending 7 min of arc, forming a square with an unfilled darker centre), surrounded by identical stationary boxes as the distractors. The displacement target was displaced vertically by square-wave oscillation at 16 Hz through an angle of 14 min. The orientation target was the letter N surrounded by the letter Z as its distractor; both target and distractor limb widths were also 1 mm. Monitor resolution exceeded that required to present the lines forming the open boxes and N and Z targets.

The subject's task was to indicate using two handheld buttons, one in each hand, the target location, either on the left or right hand side of the screen; 60 stimuli were positioned either side of the central fixation cross and targets were presented randomly in any one of these 120 locations. PAVS response times were measured using a timer incorporated in the software. Subjects were asked to complete the task as quickly as possible without sacrificing accuracy. Error responses (pressing the wrong button) were ignored in calculation of the mean response time. Error rates were less than 5% for each subject.

Procedure

Unaided vision was first recorded using a Bailey–Lovie chart. Cyclopentolate (0.5% w/v) was instilled in one eye of some subjects, usually the right eye, unless circumstances dictated otherwise. Subjective refraction and retinoscopy were performed on all subjects to ensure accurate correction of ametropia. All subjects were subjected to the same order of presentation of stimulus conditions, as indicated below (see Experiment 1: Method), including a 'no blur' condition at the beginning and again at the end of the test procedure. The eye not under test was occluded while the eye under test was optically corrected where necessary. The subject was shown a demonstration of each PAVS task, and instructed to press the relevant button as quickly as possible, once target location was identified. The subject was allowed two full practice runs through each task, a total of 240 presentations, to ensure that subjects had reached a learning plateau (Ahissar and Hochstein, 1996). The subject now began the test proper, firstly for the flicker target, followed by the displacement and then

finally for the orientation target, through the distance optical prescription (*Rx*) if any. Each single test consisted of 40 presentations of each target type, initially without optical blur (condition 'no blur 1'). Once completed, the most positive blurring lens to be used was put in the trial frame and the test was completed again. Two further lenses were used to produce blur of 2.00 and 1.00 D, respectively. Blurring was confirmed using a near visual acuity test chart at 50 cm (the viewing distance for the monitor) prior to PAVS testing. Examining the subject once more with only the distance *Rx* in place completed the test (condition 'no blur 2'). Of the 17 subjects, nine were tested with the use of cyclopentolate to induce cycloplegia, and the other eight were not. For the cyclopleged subjects, +2.00 D spheres were used to create the 'no blur' condition at 50 cm; the lenses required to produce blur were in addition to this value. For cyclopleged subjects an additional condition was presented: 2 D of simulated presbyopia, i.e. no spherical lens when viewing the monitor at 50 cm without accommodation.

Results

Repeated measures ANOVA was used separately on the two groups, cyclopleged and non-cyclopleged. The results for 'no blur 1' and 'no blur 2' reflect the condition of clear focus on the screen at 50 cm from the eye, either dependent on accommodation for those tested without cycloplegia or using a +2.00 D lens for those with cycloplegia induced.

Flicker target

Figures 2 and 3 show that simulated myopia, induced by plus lenses, had little effect on the ability of visual search

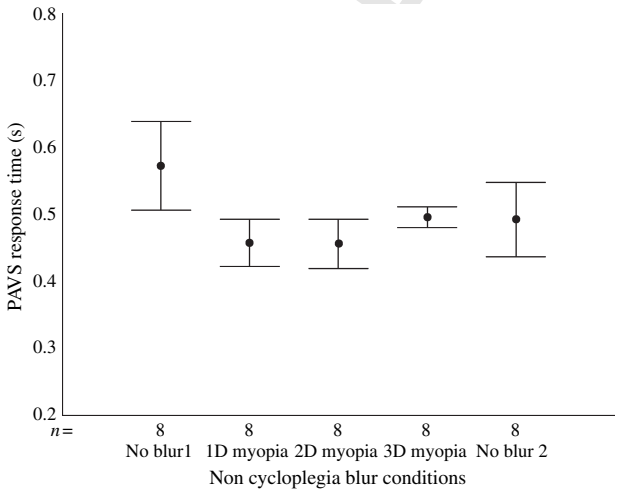

Figure 2. Effect of simulated ametropia on PAVS response times: flicker target, non-cyclopleged eyes.

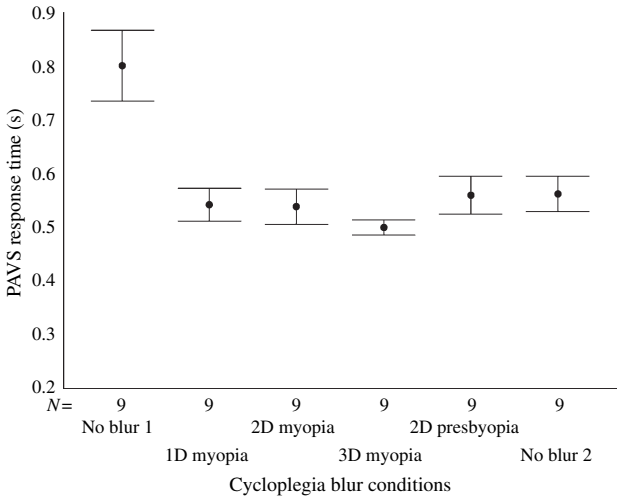

Figure 3. Effect of simulated ametropia on PAVS response times: flicker target, cyclopleged eyes.

mechanisms to detect and locate the flickering target among its distractors for subjects with or without cycloplegia. Repeated-measures ANOVA was performed separately for non-cyclopleged and cyclopleged subjects since the number of conditions was different for the two groups. Variance across 'no blur 1' and all blur conditions were non-significant for both non-cyclopleged subjects ($F = 3.366$, d.f. $= 7$, $p = 0.112$) and cyclopleged subjects ($F = 2.098$, d.f. $= 8$, $p = 0.219$). PAVS reaction times were slightly faster with 1 D blur than with 'no blur 1'; the difference may reflect a learning effect but was not statistically significant ($t = -2.01$, $p > 5\%$).

Displacement target

ANOVA results for the displacement target across all levels of blur were non-significant for both non-cyclopleged subjects ($F = 5.081$, d.f. $= 7$, $p = 0.56$) and cyclopleged subjects ($F = 3.372$, d.f. $= 8$, $p = 0.107$). However, *Figure 4* (for non-cyclopleged subjects) suggests no increase in mean response times to a displacement target under blurred conditions up to 1 D, but increased response times for levels of blur above this. Post-hoc paired t testing for this group revealed an effect for 2 D or more of blur. Thus while a non-significant difference occurred between 'no blur 1' and 1 D blur ($t = -1.586$, $p = 0.157$), a significant increase in response times occurred for 1 D blur vs 2 D blur ($t = -3.473$, $p = 0.010$).

Orientation target

Figures 6 and 7 suggest that the orientation target (N surrounded by Z distractors) was far less resistant to blur than either flickering or displacement targets.

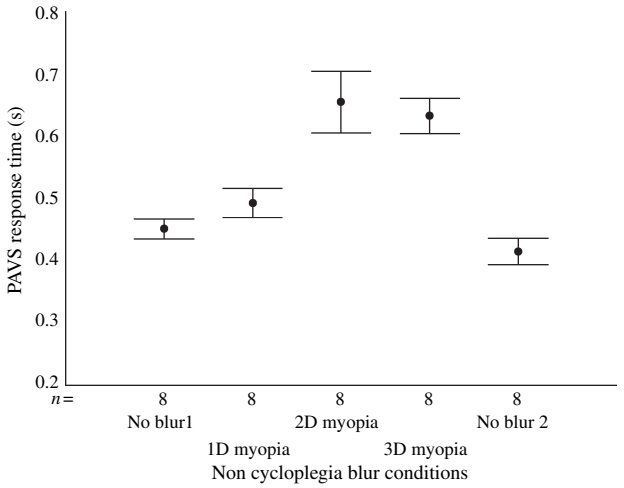

Figure 4. Effect of simulated ametropia on PAVS response times: displacement target, non-cyclopleged eyes.

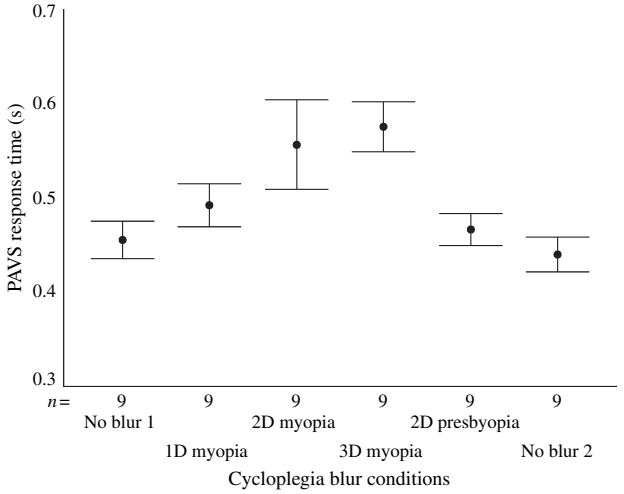

Figure 5. Effect of simulated ametropia on PAVS response times: displacement target, cyclopleged eyes.

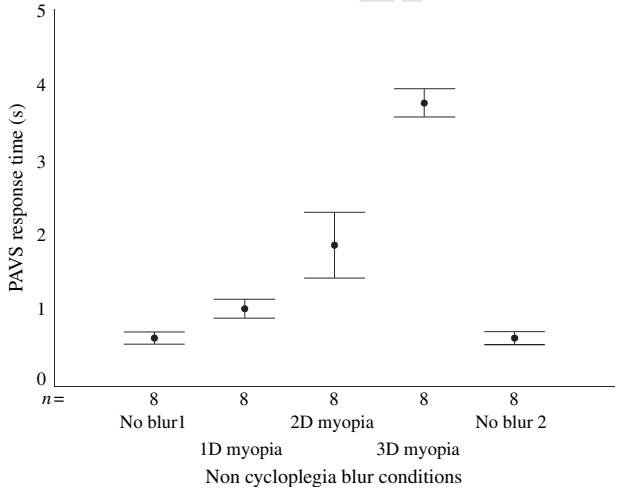

Figure 6. Effect of simulated ametropia on PAVS response times: orientation target, non-cyclopleged eyes.

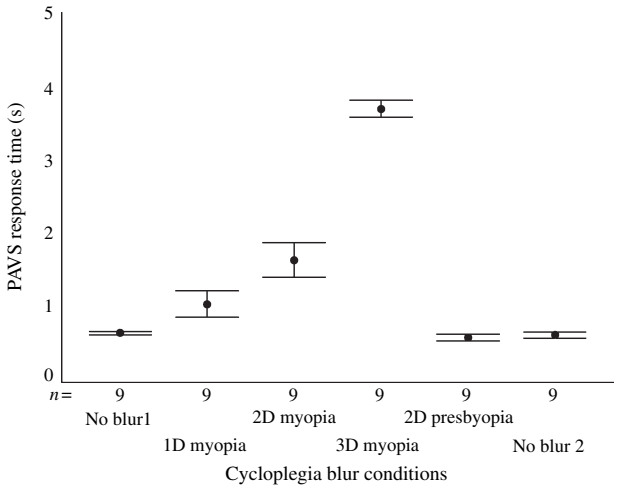

Figure 7. Effect of simulated ametropia on PAVS response times: orientation target, cyclopleged eyes.

Response times increased significantly with increasing levels of simulated myopia for both non-cyclopleged eyes ($F = 77.075$, d.f. $= 7$, $p < 0.001$), and cyclopleged eyes ($F = 484.567$, d.f. $= 8$, $p = 0.017$). Post-hoc paired t testing for non-cyclopleged eyes revealed the same effect for both groups, with significant differences occurring even between 'no blur 1' and 1 D of induced myopia ($t = 4.471$, $p = 0.010$). For cyclopleged subjects, there was no significant effect at 1 D of blur ($t = 2.0078$, $p = 0.071$), but a significant increase in response times did occur at 2 D ($t = 4.136$, $p = 0.003$).

The mean response times for subjects tested under conditions of simulated myopia of 2 D or more were dramatically increased, with mean response times increased with 2 D blur by 1.23 s for non-cyclopleged eyes and by 0.99 s for cyclopleged eyes compared to the initial 'no blur 1' condition, indicating a breakdown of parallel search, and a changeover to serial search mechanisms.

Discussion

The finding that the presence of even 3 D of blur has no statistically significant effect on visual search efficiency for a flickering target is possibly related to the fact that the distractors are out of focus and the flickering target is apparently the most visible stimulus to subjects due to its flickering nature, even though blurred on screen, such that search remains efficient despite substantial blur. Therefore it can be assumed that a high level of acuity will not be necessary to complete the flicker task efficiently. Our finding of resistance to blur using a PAVS paradigm is similar to that obtained with flicker perimetry thresholds (Lachenmayr and Gleissner, 1992). The relevance of flicker detection thresholds, as distinct from visual search time for a flickering stimulus, to glaucoma has been shown previously (Tyler, 1981).

By contrast, the oscillating target produced longer response times, possibly because of its nature – an empty box (containing no low fundamental spatial frequencies) compared to a filled white box for the flicker task. It is well known that targets containing only high spatial frequencies are degraded by blur (e.g. Charman and Jennings, 1976). Our finding of resistance to blur of up to and including +2 D for displacement targets for non-cyclopleged eyes, is similar to that reported for oscillatory movement detection thresholds (Whitaker and Buckingham, 1987), a technique with potential application for evaluation of retinal integrity behind a cataract (Barrett *et al*., 1994). The validity of movement detection thresholds to glaucoma has been noted for oscillatory movement thresholds of a line target by Fitzke *et al*. (1987), and for random dots by Silverman *et al*. (1990) and Bullimore *et al*. (1993).

However, ANOVA on cyclopleged eyes showed no significant effect of blur up to 3 D on response times. The difference for displacement targets between cyclopleged and non-cyclopleged eyes is presumably associated with the larger variance in the data for cyclopleged eyes.The decreased depth of field with dilated pupils in the former case should have increased, not decreased, susceptibility to dioptric blur.

We conclude that, within the limits of this experiment, optical defocus of up to and including 2 D will have little or no detrimental effect on visual search efficiency for flicker and displacement targets and would probably not lead to false positive results when screening for glaucoma, in which much more substantial increases in response times have been reported (Flitcroft *et al*., 1996). However the displacement target requires modification to increase its spatial frequency bandwidth to the same level as that of the flicker target to improve its resistance to blur beyond 1.5 D.

The orientation test employed a stationary target. While orientation differences are a strong stimulus to parallel search mechanisms (e.g. Wolfe, 1996), the ability of these mechanisms to locate the N among the Z distractors, was significantly reduced by the simulated myopia. The higher the degree of ametropia induced, the more inefficient the search became. The lines comprising the targets subtended 7 min at the eye, nine times the Rayleigh resolution limit of 47 s assuming light of wavelength 555 nm and a pupil diameter of 3 mm. Given a typical tenfold loss of acuity (6/6–6/60) with uncorrected ametropia of 2.00 D (Rabbetts, 1998) we would expect the lines comprising the Ns and Zs to lose visibility with this amount of dioptric blur in the present experiment. Both the target (N) and the distractors (Z) were out of focus to the same extent and, because of this, the visual system was apparently unable to decipher the orientation difference, and therefore unable to locate the target efficiently. We presume that foveal search is required and the response time slows accordingly.

Interestingly in this context, Carrasco *et al*. (1998) reported that PAVS response times are significantly longer for higher (10 cycles per degree) than lower (2 cpd) spatial frequencies for gratings embedded in Gabor patches within a central 14° field. The lines comprising our N and Z targets may be considered as elements of square wave gratings with a fundamental spatial frequency of 4.3 cpd. However, our initial observations suggest that broadening the line width appears not to reduce response times under blurred conditions.

In general it can be seen that for both the flickering and displacement targets, simulated myopia of up to 3.50 D (uncorrected blur of 1.5 D), and presbyopia of up to 2.00 D, did not interfere with visual search efficiency in that ANOVA showed no statistically significant increase in mean response times was found across all blur levels. Indeed a relative enhancement of performance occurred when the distractors were sufficiently out of focus even at levels of blur up to 3 D. The orientation target however cannot be located easily, with response times increasing as the level of blur increases.

It would be useful to investigate whether similar findings would occur among subjects with naturally occurring uncorrected ametropia and presbyopia. We plan to investigate the effects of both age and media opacities in further studies. If the pattern of the above results continues in such cases, then it would appear that use of an orientation PAVS target would require optical correction of subjects before PAVS testing.

Many attempts have been made to devise new psychophysical tests to evaluate the functional integrity of the optic nerve, and detect glaucomatous damage at the earliest possible stage of the neuropathy (e.g. Fitzke *et al*., 1987; Wall and Ketoff, 1995; Johnson and Samuels, 1997; Wall *et al*., 1997). Conventional tonometric, ophthalmoscopic and perimetric techniques are all flawed to the extent that currently glaucoma cannot be diagnosed until a substantial proportion of optic nerve fibres have been significantly damaged and even destroyed (Quigley *et al*., 1988). Therefore, new diagnostic techniques are required. A PAVS test, such as a modified version of that used in the present study, provides one possible solution (Flitcroft *et al*., 1996). Whether this test is equivalent to or more sensitive than currently available tests remains to be evaluated.

PAVS is subject to a learning effect (Ahissar and Hochstein, 1996). We are currently investigating the time-course of the effect; this will indicate the number of pre-test trials likely to be necessary for our test configuration in a clinical environment.

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Appendix

We have assumed in this paper that visual search was pre-attentive and involved parallel rather than serial search. Support for these assumptions comes from two findings. Firstly, if we assume that 10 ms^{-1} search time or greater per item provides a working definition of serial search, we would expect the serial search time for 120 items to be 1.2 s or greater. This value was never exceeded with flicker or displacement targets regardless of degree of blur, though mean response times did exceed this value for the orientation target with 2 or more dioptres of blur.

A commonly assumed feature of pre-attentive visual search is that search time is almost independent of the number of distractors. In this context, we found that the mean simple and complex reaction times using just two targets but otherwise identical conditions (0.31 and 0.40 s, respectively) are close to those obtained using our PAVS paradigm with 119 distractors (e.g. 0.47 s for the oscillating target without dioptric blur).

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