Effect of a cataract simulation on clinical and real world vision

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Abstract

Aims/background—Many reports have indicated that some patients with cataract can retain good visual acuity but complain of significant visual problems. This is the first in a series of papers trying to determine what causes these symptoms and whether other clinical tests can predict the real world vision loss.

Methods—The effect of a cataract simulation with a similar angular distribution of light scatter as real cataract on clinical (visual acuity, contrast sensitivity, and disability glare) and real world vision (face recognition, reading speed, and mobility orientation) was investigated.

Results—The simulation had a relatively small effect on visual acuity (6/6 with the simulation), but much larger effects on contrast sensitivity and low contrast acuity with and without glare. The simulation had no effect on high luminance and high contrast real world tasks, such as mobility orientation in room light and optimal reading speed. A small, but significant deterioration was found for the slightly lower contrast task of face and expression recognition. However, under low luminance conditions, substantial defects in mobility orientation were obtained (despite 6/6 acuity).

Conclusions—Although the relative effect of the cataract simulation on acuity and contrast tasks is not typical of the average cataract, it can be found in those cataract patients with visual problems despite good visual acuity. This corroborates the suggestion that it is large amounts of wide angle light scatter (forward and/or backward) which are at least partly responsible for visual disability in cataract patients with good visual acuity. A patient's reported visual disability may depend on the percentage of time he or she spends under low contrast and/or low luminance conditions, such as walking or reading in dim illumination, and walking or driving at night, in fog, or heavy rain.

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There is a vast body of literature reporting the use of clinical vision tests to discriminate between diseased and normal eyes, to assess disease progression, and to evaluate the effects of intervention. Relatively little attention has been paid, however, to the use of clinical vision testing to predict real world performance. Visual acuity testing, for example, is employed to determine whether an individual is allowed to drive and to categorise a patient as legally blind, yet there are little or no data on the relation between a given level of visual acuity and an individual's ability to perform everyday visual tasks. In essence, all of our clinical vision tests are surrogate measures for real world performance but there is a paucity of data relating the two. The literature that does exist provides conflicting evidence. For example, three studies have searched for clinical test correlates of orientation and mobility of low vision individuals.[1-3] All found a strong correlation between visual field loss and mobility orientation performance, but Marron and Bailey[1] found no correlation between mobility orientation performance and visual acuity, unlike Brown and colleagues[2] who reported them to be closely related. Similar conflicting evidence is found when clinical tests are compared with face perception and reading. Bullimore *et al*[4] found face recognition to be most highly correlated with visual acuity (specifically for word targets) while others have found the best correlation with contrast sensitivity.[5-7] Peak reading speed in low vision subjects has, in different studies, been found to be correlated best with word reading acuity[8 9] and contrast sensitivity.[10] Many of the discrepancies can be accounted for by differences in test design, the range of vision tests employed, and the populations tested. For example, if the recognition of face targets is assessed by varying contrast[6] then it is more likely to correlate with contrast sensitivity measures. If the face recognition threshold is measured by adjusting face size, then the scores are more likely to correlate with visual acuity.[4]

The relation between real world performance and clinical tests of vision is particularly germane in the case of cataract. Cataract extraction is the most commonly performed ocular surgery, and it is argued that the need for cataract extraction is indicated when the quality of the patient's day to day life is impaired. Because it can be difficult to justify surgery purely on the basis of patient's symptoms, and because there is so little information on the relation between real world vision and clinical tests in cataract, guidelines emphasise that surgery is indicated when a certain level of visual acuity has been reached.[11] This is despite substantial evidence that visual acuity is a poor indicator of real world vision in some cataract patients.[12-17] The AHCPR Clinical Practice Guidelines[11] and the American Academy of Ophthalmology report on contrast sensitivity and disability glare[16] suggest that studies of how real world vision loss compares with clinical test results in patients with cataract are essential.

This is the first in a series of studies to investigate the relation between clinical tests of vision and real world visual performance in cataract. In early cataract, visual disability is principally caused by increased forward light scatter leading to reduced retinal contrast.[16-18] It has been suggested that patients with media opacities with good visual acuity who complain of significant visual problems are those with large amounts of wide angle light scatter.[18 19] To investigate this suggestion, we examined the effects of a wide angle light scattering medium on clinical and real world vision. Various 'cataract simulations' have been used in previous studies to assess the effect of light scatter on resolution and contrast,[20] visual field measurements,[21 22] mobility orientation,[23] and driving performance.[24] However, none of these studies evaluated the angular distribution of the light scatter produced by their simulations, yet this determines the effect of light scatter on the point spread function and thus the contrast sensitivity function.[18] Several light scattering media were assessed and one was chosen which gave a similar angular distribution of wide angle light scatter as the normal[25] and cataractous eye.[18 26] The angular distribution of wide angle light scatter has been shown to be similar for the three main morphological cataract types of cortical, nuclear, and posterior subcapsular.[18] The relatively greater effect of posterior subcapsular cataract on vision compared with the other types is probably due to the substantial loss of vision which occurs with reduced pupil size with this cataract.

Clinical vision (visual acuity, contrast sensitivity, and disability glare) and real world vision (face recognition, reading speed, and mobility orientation) were then measured in 20 young subjects, both with and without the chosen scattering medium.

Figure 1   A plot of luminance emanating from the Vistech cataract simulation against angle. The −2 exponent of the power relation which characterises the scattering distribution is similar to the wide angle light scattering in normal and cataractous human eyes.

ment. Measurements at angles either side of zero were averaged, and a graph of luminance emanating from the scatter cell against angle was plotted (Fig 1). The Vistech cataract simulation was found to scatter light with a similar angular distribution as cataract (light scatter being inversely proportional to the square of the angle) and was hence chosen for the present study (Fig 1). Other features such as its spectacle mounting and availability are additional useful qualities. The Vistech cataract simulation is provided with the Vistech contrast sensitivity system to enable practitioners to illustrate to patients the effect of reduced contrast on vision. The picture through the simulation is very 'washed out', although a reasonable sharpness to the edges of objects is retained.

Methods

SELECTION OF LIGHT SCATTER MEDIUM
Beyond 3 degrees of visual angle from its centre, the point spread function declines in amplitude in approximately inverse proportion to the square of the visual angle for both normal and cataractous eyes.[18 25 26] To mimic wide angle intraocular light scatter, a similar angular light scatter distribution should be provided. We assessed the light scatter distribution of the Vistech cataract simulation and various optical cells which have been used previously in our laboratory.[27] The collimated beam of light from a tungsten filament incandescent lamp was directed onto the front surface of the scatter simulation. A computer controlled spectrophotometer (Bentham Instruments Ltd) was used to measure the luminous flux emanating from a fixed area on the rear surface of the illuminated scatter simulation. The light source and the scatter media were mounted on a rotatable optical bench, enabling photometric measurements to be made at angles between 5 and 20 degrees from the filament. Measurements at angles less than 5 degrees were unreliable owing to the extended (non-point source) nature of the fila-
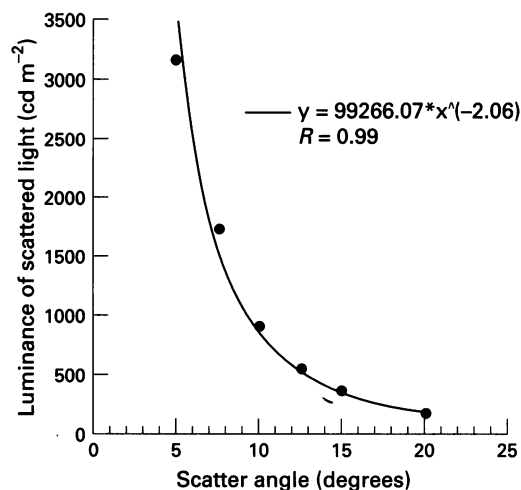
SUBJECTS
Thirty young subjects (mean age 24.5 (SD 4.1) years) were recruited. The tenets of the Declaration of Helsinki were followed and the study gained ethical approval from the University's Office of Human Research. Informed consent was obtained after the nature of the study had been fully explained. The clinical and real world vision assessments were made on 20 subjects with and without the Vistech simulation. Ten subjects were tested twice without the simulation to determine any learning effects. All measurements were made binocularly with natural pupils and with the subject's own habitual refractive correction (if any).

CLINICAL VISUAL ASSESSMENT
Clinical measurements consisted of binocular Bailey–Lovie high contrast visual acuity, low contrast visual acuity with and without glare, and Pelli–Robson contrast sensitivity. All of these tests have previously been shown to provide reliable measurements.[28] Bailey–Lovie high contrast logMAR visual acuity was measured at 6 metres. LogMAR charts have become the standard for clinical research as they have

many advantages over traditional Snellen charts including the provision of non-truncated data down to 6/3, a geometric progression of letter size that has been shown to provide equal increments in legibility, five letters on each line, and letters of similar legibility. MAR is the minimum angle of resolution, so that 6/6 has a MAR of 1 minute of arc and a logMAR value of 0.0. The chart contains 13 lines in 0.1 log unit steps from −0.3 logMAR (6/3) to 1.0 logMAR (6/60). A chart luminance of 100 cd/m^2 and a by letter scoring system (0.02 log units per letter) was used. The Berkeley glare test consists of a reduced low contrast Bailey–Lovie chart (Michaelson contrast = 10%, Weber contrast = 18%) mounted on a triangular opaque panel at the centre of a 30 × 27 cm opal Plexiglass panel. The chart is front illuminated (80 cd/m^2) and the glare source provided by transillumination of the Plexiglass panel. At the medium setting the glare source luminance is 750 cd/m^2. Measurements of low contrast visual acuity were made at 1 metre with and without the glare source, with credit (0.02 log min arc) given for each letter read correctly. The Pelli-Robson chart is a 86 × 63 cm chart containing 4.9 × 4.9 cm letters arranged in 16 triplets. At a test distance of 1 metre these letters correspond to a spatial frequency of about 1 c/deg. Within each triplet the letters have the same contrast and the contrast in each successive triplet decreases by a factor of 0.15 log units. The chart luminance was 100 cd/m^2 and a by letter scoring system which gives credit (0.05 log units) for each letter read correctly was used.

REAL WORLD VISION ASSESSMENT
Three real world tasks were adopted to assess real world vision:
1 mobility orientation
2 reading speed
3 face recognition.
Safe travel relies on our ability to use and interpret visual information and select and implement adaptive strategies. Adaptive strategies used for locomotion over uneven terrain include obstacle avoidance by appropriate step length, width and height adjustments, and steering. Rather than study each of the many adaptive strategies in isolation, three travel paths were designed that required most adaptive strategies to be implemented by the subjects. These included a variety of obstacles, both on and above ground, of different shapes, sizes, and contrast placed in a variety of configurations. The travel paths were challenging and required continuous visually guided modifications to the gait patterns to travel without bumping into objects and staying within the boundaries of the path. This approach evaluates the robustness of the visual perception (including visual attention and search skills) and action (changes in upper and lower body movements during locomotion) coupling. Mobility performance was assessed by recording the time needed to travel the path and the number of 'mistakes' made by the subject. A mistake was defined as contact with an
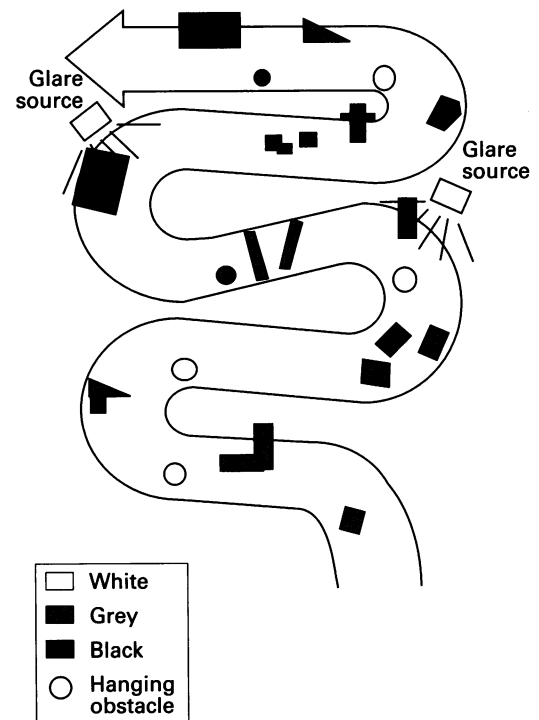

Figure 2 A schematic diagram of one of the travel pathways used to assess mobility orientation.

obstacle, coming to a complete stop, straying outside the pathway, and avoidance strategies when none were required—for example, changing locomotor patterns when no obstacles were present. Patients with cataracts and other media opacities particularly complain of problems in dim illumination and in the presence of glare sources—for example, night driving.[14][29] The illumination for two of the courses was dim—that is, < 1 lux to simulate twilight, and two of the three travel paths included appropriately placed glare sources. The third course had illumination in the photopic range—that is, ~ 450 lux, consistent with normal room illumination. A diagram of one of the courses is shown (Fig 2).

Reading speed was measured by having patients read Bailey–Lovie word charts at 40 cm. These are non-continuous text charts with print ranging in size from 10 M to 0.25 M (80 point to 2 point) in 0.1 log unit steps. Subjects read aloud and were taped for analysis at a later time. Each subject read three different word charts. Reading speed for each print size was calculated in words per minute, and was averaged across the three charts. Consistent with previous reports,[9] reading speed was relatively constant for print sizes greater than five lines above threshold size. Reading performance was determined as the mean of the two peak speeds.

Face recognition was assessed using the method developed by Bullimore and colleagues.[4] Black and white photographs of four male and four female faces were selected from 'Pictures of facial affect' (Consulting Psychologists Press, Palo Alto, CA, USA). For each individual, there were four different facial expressions—happy, sad, angry, and afraid/surprised, giving a total of 32 photographs. The photographs were cropped to remove the

Table 1 Mean (SD or range) of the binocular clinical and real world vision test results for 20 young subjects.

		Normal condition	With Vistech simulation
Clinical tests:			
LogMAR visual acuity		−0.15 (6/4)* (0.07)†	−0.01 (6/6)* (0.06)†
Log contrast sensitivity		2.04 (0.08)	1.36 (0.07)
LogMAR low contrast VA		0.12 (6/7.5) (0.07)	0.48 (6/18) (0.10)
LogMAR low contrast VA with glare		0.15 (6/9) (0.06)	0.95 (6/60) (0.02) (n=11)
Face recognition:			
LogEVD for identity		1.54 (35 m) (0.06)	1.46 (29 m) (0.06)
LogEVD for expression		1.54 (35 m) (0.04)	1.47 (30 m) (0.07)
Reading:			
Log word acuity		−0.06 (6/5) (0.07)	0.04 (6/6) (0.10)
Peak reading speed in log words/min		1.97 (93 wpm) (0.09)	1.99 (98 wpm) (0.10)
Mobility:			
Dim illumination with glare	Mistakes	0.9 (1.0)	5.3 (3.1)
	Time (s)	27 (6)	38 (10)
Dim illumination	Mistakes	0 (0–1)	6.5 (2.6)
	Time (s)	27 (5)	45 (12)
Bright illumination with glare	Mistakes	0 (0–1)	0 (0–1)
	Time (s)	18 (5)	20 (4)

*Approximate equivalent Snellen visual acuity values are given in parentheses.
†Standard deviation.

hair outline so that identification was predominantly dependent on the facial features. Thirty of these photographs were arranged in a letter chart format. There were five faces per line with each line decreasing in size by 0.15 log units. The angular size of the faces was expressed in terms of the equivalent viewing distance (EVD), the distance at which a real face would subtend the same angle that the photograph subtends. The subject's performance was scored in the same way as the visual acuity charts with credit given (0.03 log units) for each correct answer. Two threshold scores were obtained: for correct recognition of identity and for correct recognition of expression. During testing subjects could refer to a panel with large photographs of the eight characters in neutral facial expressions.

Results

There were no significant differences between the test and retest data of the 10 subjects using two tailed *t* tests. This indicates there were no significant learning or fatigue effects. The mean and standard deviations for the clinical and real world vision tests, with and without light scatter, from 20 subjects are shown in Table 1. The number of mistakes during the travel paths without the light scatter were highly skewed for the dim illumination and normal illumination conditions, with most subjects not making any mistakes. Median and range data are therefore given for these conditions rather than mean and standard deviations. In addition, nine of the 20 subjects could not see any of the letters on the low contrast visual acuity chart under glare conditions with the light scatter.

The scattering medium induced little change in visual acuity (0.14 logMAR or one and a half lines), mobility orientation in normal room illumination (no increase in mistakes, 11% increase in time), face recognition (5 metre change in equivalent viewing distance), word acuity (0.10 logMAR or one line), and reading speed (5 words per minute increase). The slight effect on visual acuity meant that an average high contrast visual acuity of 6/6 was obtained with the cataract simulation. More

substantial deficits were produced, however, in contrast sensitivity (0.68 log contrast sensitivity or four and a half lines on the chart), low contrast visual acuity with (at least 8 lines of visual acuity) and without glare (three and a half lines), mobility orientation in dim illumination (six additional mistakes, 67% increase in time), and in dim illumination with glare (five additional mistakes, 41% increase in time). All these differences were statistically significant using two tailed *t* tests (p<0.001) except for the time taken and the number of mistakes in the normal room illumination with glare and the optimal reading speed. The slightly greater reduction in mobility in dim illumination compared with when a glare source was added indicate that the glare source improved vision by increasing room illumination, and this effect was greater than any reduction in vision due to disability glare.

Discussion

The normal data are similar to previously published binocular data of visual acuity and Pelli–Robson contrast sensitivity in young subjects.[30] The visual acuity data are slightly poorer than previously reported and may reflect the use of subjects' habitual rather than optimal refractive corrections.

The cataract simulation produced a contrast sensitivity:visual acuity loss ratio of 4.5 (Table 1). Pardhan and Elliott[30] reported a contrast sensitivity:visual acuity loss ratio of 1.9 between patients with cataract and age-matched controls. The relatively greater effect of the cataract simulation on the contrast sensitivity:visual acuity ratio compared with data reported for cataract may be because the scattering medium is only providing wide angle light scatter (beyond 5 degrees) of the same angular distribution as cataract. This suggests that an average cataract influences visual acuity by a much greater extent than the Vistech cataract simulation. This is most probably due to a relatively greater amount of narrow angle light scatter in the average real cataract (less than about 1 degree), but could be due to effects other than light scatter in cataract—for example, irregularities of refractive index or aberrations.

However, it is not average cataract patients we are interested in as their vision is reasonably well described by traditional visual acuity measurements.[12][19] We are interested in the 10–20% of cataract patients who have reasonable acuity, but complain of visual problems in the real world.[12] [19] The cataract simulation caused increased wide angle light scatter with an angular distribution similar to cataract and caused minimal loss to visual acuity, yet a significant reduction in walking ability in dim illumination. These findings corroborate the suggestion that wide angle light scatter is the cause of complaints of significant visual disability in patients with cataract with good visual acuity.[18][19] This could be due to increases in both forward and backward light scatter. The Vistech simulation had two effects on vision: it reduced retinal contrast due to increased forward light scatter and reduced retinal illumination due to increased backscatter. The latter effect is expected to be significant only at low light levels. The poor mobility orientation in dim illumination could be due to increased forward scatter reducing retinal contrast or increased backscatter reducing retinal illumination. A contrast sensitivity or glare test could be used to clinically assess forward light scatter and the large reductions in contrast sensitivity and disability glare caused by the cataract simulation are evidence of their relatively greater sensitivity to forward light scatter compared with visual acuity. Many reports have suggested that low spatial frequency contrast sensitivity and/or glare testing should be used to complement visual acuity testing in early cataract.[14-16] [19] The lack of an effect of the simulation on mobility orientation in normal illumination suggests that it is the reduction in contrast or illumination of the simulations which is decreasing mobility orientation in dim illumination rather than a restriction of the field of view due to the spectacle mounting. Backscatter can be assessed clinically in patients with cataract using the slit-lamp. Whether wide angle light scatter reduces real world performance at low illumination levels because of increased forward or backward light scatter will be investigated in subsequent studies.

The fact that reading, face recognition, and mobility orientation performance in normal illumination are relatively unaffected by the light scatter implies that these real world vision tasks are relatively immune to reductions in retinal contrast at the light levels used. This is consistent with previous research.[31][32]

Although we found no significant change with the cataract simulation in mobility orientation in normal room illumination, very significant deteriorations in performance were found under twilight conditions. We suggest that cataract patients (and other patients with low vision[23]) may have sufficiently good vision to travel when illumination is good, but do not when illumination is poor. Other research suggests that cataract and low vision patients are selective about when they go out walking and driving. Genensky and colleagues[33] found that almost all of their 94 legally blind patients

(caused by a variety of conditions) walked outdoors by themselves (at least in well known areas), but less than half travelled alone at night. It is well known that patients with cataract tend to avoid difficult driving conditions, such as driving at night.[34] The increase of five to six 'mistakes' in the dim illumination pathways due to the cataract simulation indicates the seriousness of the reduction in mobility orientation performance in these light levels, despite 6/6 visual acuity. This suggests that a good acuity may not ensure safe mobility orientation in dim illumination in patients with cataract and other media opacities. Serious injury caused by falls is a significant problem in the aging adult. It has been suggested that falls cause more than two thirds of the accidental deaths in the over 75 age group.[35] The 40–66% increases in travel time found in the dim illumination paths should also be considered. The consequences of increases in travel time, such as when crossing a road, can also be serious.

In summary, our results indicate wide angle light scatter can cause large reductions in contrast sensitivity and disability glare, but have minimal effects on visual acuity. Subjects with induced wide angle light scatter can also be seriously disabled at some real world vision tasks such as walking in dim illumination. These findings corroborate the suggestion that wide angle light scatter could cause complaints of significant visual disability in patients with cataract who have reasonable visual acuity. The results further suggest that a cataract patient with good visual acuity should have minimal problems visually if the illumination conditions are good. Their reported visual disability will probably depend on the percentage of time that they spend under low contrast and/or low luminance and/or glare conditions, such as walking or reading in dim illumination, night driving, and walking or driving in fog or heavy rain. In particular, a visual acuity as good as 6/6 does not ensure that a cataract patient with significant wide angle light scatter is safe to walk under poor illumination conditions. Contrast sensitivity and glare tests may be better representatives of these patients' vision than visual acuity. This hypotheses will be further explored in subsequent reports which will discuss results from cataract patients, both before and after surgery.

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