CLINICAL SCIENCE

Factors associated with undercorrected refractive errors in an older population: the Blue Mountains Eye Study

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Aims: To identify characteristics of people with clinically relevant undercorrected refractive errors.
Methods: The Blue Mountains Eye Study was a population based survey of 3654 Australians aged 49–97 years. Examinations included a standardised refraction and measurement of presenting and best corrected visual acuity. Clinically relevant undercorrected refractive error was defined as improvement of ⩾10 letters (2+ lines on the logMAR chart) in subjects with presenting acuity 6/9 or worse. Associations with a range of demographic and ocular variables were explored, adjusting for age and sex, presented as odds ratios (OR) with 95% confidence intervals (CI).
Results: Undercorrected refractive error was present in 814/3654 subjects (10.2%). Older age (p <0.001), hyperopia (OR 1.45, CI 1.15 to 1.83), longer interval from last eye examination (p <0.001), past occupation as tradesperson (OR 1.64, 1.13 to 3.29) or labourer (OR 2.00, CI 1.39 to 2.89), receipt of government pension (OR 1.47, CI 1.12 to 1.94), and living alone (OR 1.34, CI 1.05 to 1.72) were all associated with undercorrected refractive error. Past or current use of distance glasses (OR 0.25, CI 0.20 to 0.32) and driving (OR 0.67, CI 0.52 to 0.86) were associated with a lower prevalence.
Conclusions: Increasing age and measures of socioeconomic disadvantage and isolation were found to predict undercorrected refractive error. Given the documented impacts from correctable visual impairment, these findings suggest a need to target education and eye care services.

Recent reports have highlighted the impacts of visual impairment on the independent living of older people, including effects on use of community support services, falls and fractures, general health, nursing home placement, and mortality.[1–12] Although the magnitude of these impacts has been found to be greatest for irreversible refractive error, a number of reports have also shown that presence of undercorrected refractive error was also associated with significant morbidity.[13 14]

While a number of reports have indicated a relatively high frequency of undercorrected refractive errors in older populations, few recent studies have explored associated factors. [15] Investigators from the Baltimore Eye Survey reported that 54% of their participants improved their vision by at least one line on the Snellen chart with refraction.[16] More recently, the Melbourne Visual Impairment Project[17] found that 57% of subjects presenting with a visual acuity of 6/6 minus two letters were able to improve their vision by one line or more with refraction. A previous report from our own survey (the Blue Mountains Eye Study) had also indicated that a large proportion of subjects had undercorrected refractive error: 45.3% of participants were able to improve their visual acuity by one or more lines in the right eye.[18]

The aim of this study is to delineate some of the demographic, social, and eye related variables that are associated with undercorrected refractive error in our study sample. By identifying the features of people with this condition, it is hoped that in the future eye care services can be specifically structured to target those that might be affected.

METHODS

The Blue Mountains Eye Study (BMES) was a population based survey of common eye diseases conducted in a two postcode area, west of Sydney, Australia. All permanent residents, aged 49 years or older were invited to participate during the period 1992–4. Ethical approval for the study was granted by the Western Sydney Area Health Service human ethics committee, and signed informed consent obtained from all participants. The examination included an interviewer administered questionnaire and a comprehensive eye examination. The study has been described in detail elsewhere.[18]

Subjects were asked their place of birth, current employment status, and main past occupation. Ability to speak English was assessed with the question "At home do you usually speak a language other than English?" Further questions assessed education after leaving school, receipt of a government pension, being a current driver, and history of any car accidents in the past year.

Participants were asked to rate their overall health status as excellent, good, fair, or poor. Questions were asked about specific diseases including cancer, diabetes, arthritis, ischaemic heart disease, and hypertension. Level of dependence on others was assessed by asking participants if they were able to go out alone, to town, to visit friends or to shop and whether they lived alone or used community support services, including meals on wheels, home help, and home nursing.

Visual acuity was measured using a logarithm of the minimum angle of resolution (logMAR; Vectorvision CSV 1000, Vectorvision Inc, Dayton, OH, USA) chart. The chart was retroilluminated with automatic calibration to 85 cd/m^2 and read at 8 feet. Presenting visual acuity was assessed initially with the subject's current glasses, if worn. An objective refraction was then performed on all participants, using a Humphrey 530 Automatic Refractor (Allergan Humphrey). For all subjects with a presenting visual acuity of <54 letters read correctly (6/6 Snellen equivalent), the autorefractor correction was placed in a trial lens frame and a subjective refraction was performed using the Beaver Dam Eye Study modification of the Early Treatment Diabetic Retinopathy Study protocol.[19] Refractive error was tested in 0.25D steps. Both 0.25D and 0.5D Jackson Cross cylinders were used to test cylinder power, which was recorded in the negative form. For

Table 1 Prevalence of undercorrected refractive error in study sample

Number of lines improved (presenting visual acuity)*	Number of subjects with undercorrected refractive error	% of total (n=3654)
⩾1 line (<50 letters)	889	24.3
⩾2 lines (<45 letters)	371	10.2
⩾3 lines (<40 letters)	167	4.6
⩾4 lines (<35 letters)	71	1.9

*For each level of undercorrected refractive error, the level of presenting visual acuity was selected to permit improvement to a maximum of 6/6 Snellen equivalent.

each eye, best corrected visual acuity was recorded as the number of letters read, following refraction, from 0–70.[20]

Slit lamp and retroillumination lens photographs were taken to determine the presence of cataract, and graded as described previously.[21 22] History of past cataract surgery was confirmed at examination. Presence of late stage age related maculopathy (ARM) was evaluated from stereoscopic retinal photographs.[23] Open angle glaucoma was diagnosed by the presence of matching typical glaucomatous visual field loss on automated perimetry and optic disc cupping with rim thinning, as described.[24] Participants were asked when they had last seen an optometrist or ophthalmologist, and whether they had ever worn glasses to see clearly in the distance and whether they had noticed a change in their vision.

The spherical equivalent refraction (SER) used the formula (sphere + cylinder/2). Hyperopia was defined as SER ⩾ +1.00 dioptres and myopia as SER ⩽-1.00 dioptres. We categorised corrected visual acuity into three groups, based on the number of letters read correctly after refraction: 54–70 letters, 41–53 letters, and < 41 letters.

We defined clinically relevant undercorrected refractive error as an improvement of ⩾10 letters (two lines on the logMAR chart), after refraction in subjects with a presenting visual acuity <45 letters (6/9 Snellen equivalent). For each participant, the eye with the better presenting visual acuity was selected for analysis. This definition of undercorrected refractive error was chosen as it represents a clinically relevant level, and differs slightly from that of our previous report by Attebo *et al*.[18] A second criterion defining a more severe level of

Table 2 Age and sex adjusted associations between demographic and systemic variables and undercorrected refractive error; 2 or more line improvement in participants with presenting visual acuity (VA) <6/9

Variable	Number with presenting VA <6/9	⩾2 line improvement (%)	OR (95% CI)	p Value
Sex				
Men	169	45.6	1.14 (0.91 to 1.41)	0.25
Women	202	54.4	1.00 (reference)	
Age group (years)				
45–59	56	15.1	1.00 (reference)	
60–69	127	34.2	1.85 (1.34 to 2.56)	0.002
70–79	128	34.5	2.67 (1.92 to 3.70)	0.0001
⩾80	60	16.2	3.43 (2.33 to 5.06)	0.0001
Principal occupation				
Professional/managerial	95	25.6	1.00 (reference)	
White collar	91	24.5	0.97 (0.71 to 1.32)	0.84
Trade	51	13.7	1.64 (1.13 to 2.39)	0.01
Labourer	53	14.3	2.00 (1.39 to 2.89)	0.0002
Current occupation				
House duties	58	15.6	1.00 (reference)	
Retired	238	64.2	1.13 (0.82 to 1.58)	0.46
Employed	49	13.2	0.89 (0.56 to 1.41)	0.63
Unemployed/other	16	4.3	1.19 (0.64 to 2.22)	0.58
Language spoken at home*	13	3.5	0.71 (0.40 to 1.27)	0.25
Region of birth				
Australia	248	66.8	1.00 (reference)	
NZ/Oceania	61	16.4	0.86 (0.64 to 1.16)	0.32
Europe	42	11.3	1.29 (0.91 to 1.83)	0.16
Asia/other	12	3.2	1.62 (0.86 to 3.06)	0.14
Further education†	183	49.3	0.80 (0.64 to 1.00)	0.05
Receipt of government pension	262	70.6	1.47 (1.12 to 1.94)	0.006
Current driver	206	55.6	0.67 (0.52 to 0.86)	0.002
Car accident in past year	11	3.0	0.89 (0.47 to 1.68)	0.71
Use community support services	27	7.3	1.06 (0.68 to 1.66)	0.79
Living alone‡	134	36.1	1.34 (1.05 to 1.72)	0.02
Independent‡§	277	74.7	0.94 (0.46 to 1.95)	0.88
Self rated health				
Excellent	62	16.7	1.00 (reference)	
Good	203	54.7	1.17 (0.87 to 1.58)	0.31
Fair	83	22.4	1.18 (0.83 to 1.68)	0.35
Poor	17	4.6	1.25 (0.70 to 2.23)	0.45
Systemic illnesses				
Cancer	30	8.1	0.87 (0.58 to 1.29)	0.48
Arthritis	185	49.9	0.95 (0.76 to 1.19)	0.64
Diabetes	28	7.5	1.28 (0.84 to 1.94)	0.25
Ischaemic heart disease	65	17.5	0.95 (0.71 to 1.27)	0.72
Hypertension	153	41.2	0.99 (0.79 to 1.23)	0.92

*Reference group = people only speaking English at home.
†Attainment of a trade certificate or higher education after leaving school.
‡Also adjusted for current driving status.
§Able to go to town, to shop or visit someone alone.

Table 3 Age and sex adjusted associations between ocular variables and undercorrected refractive error; 2 or more line improvement in participants with presenting visual acuity (VA) <6/9

Variable	Number with presenting VA <6/9	⩾2 line improvement (%)	OR (95% CI)	p Value
Hyperopia	200	53.9	1.45 (1.15 to 1.83)	0.002
Myopia	47	12.7	1.06 (0.77 to 1.48)	0.71
Corrected visual acuity				
54–70 letters	250	67.3	1.00 (reference)	
41–53	103	27.8	1.33 (1.01 to 1.74)	0.04
<41	18	1.3	0.70 (0.40 to 1.22)	0.21
Time since last eye examination				
<3 years	222	59.8	1.00 (reference)	
3–<5 years	57	15.4	1.50 (1.10 to 2.05)	0.01
⩾5 years	79	21.2	2.10 (1.58 to 2.78)	0.0001
Visual symptoms*	57	15.4	1.07 (0.78 to 1.48)	0.68
Uses distance glasses†	167	45.0	0.25 (0.20 to 0.32)	0.0001
Nuclear cataract†	49	13.2	1.11 (0.75 to 1.63)	0.61
Cortical cataract†	76	20.5	0.98 (0.72 to 1.32)	0.88
Posterior subcapsular cataract†	18	4.9	1.33 (0.77 to 2.30)	0.30
Previous cataract surgery	19	5.1	0.81 (0.49 to 1.35)	0.42
Open angle glaucoma†	12	3.2	1.08 (0.56 to 2.06)	0.83
Age related macular degeneration	10	2.7	0.79 (0.39 to 1.60)	0.52

*Self rated deterioration in vision.
†Adjusted also for longer duration since last eye examination.

correctable refractive error was an improvement of 15 or more letters in subjects with presenting visual acuity <40 letters (6/12 Snellen equivalent).

Statistical analysis
Logistic regression analyses were performed using the Statistical Analysis System (SAS Institute, Cary, NC, USA). Univariate, age-sex adjusted, and multivariate analyses were performed. p Values <0.05 were taken to indicate statistical significance. Mantel-Haenzsel tests for trend were calculated to assess the effects of age and time since eye examination. For vision and eye disease variables, values for the eye with the better presenting visual acuity were used in analyses.

RESULTS
Of the 4433 eligible subjects, 3654 people aged 49–97 years (82.4% response) participated, including 2072 women (56.7%) and 1562 men (43.3%), with a mean age of 66.2 years. Refraction data were missing on 12 subjects. Most subjects were older than 60 years (72.1%) and retired from employment (54.1%). The majority were born either in Australia, New Zealand, or Oceania (85.6%) and 92.3% spoke only English at home. A high proportion (73.5%) of subjects rated their general health as either good or excellent.

Among study participants, there were 814 (22.3%) with presenting visual acuity <45 letters (6/9 or worse), including 371 (10.2%) with undercorrected refractive error, using the two line criterion. In almost half these cases (45.0%), presenting visual acuity was <40 letters and improved by three or more lines with refraction. Table 1 shows the prevalence of different levels of undercorrected refractive error.

Table 2 shows associations among demographic, social, general and medical health factors with undercorrected refractive error, after adjusting for age and sex. Age and sex adjusted associations with ocular factors are shown in Table 3.

Increasing age (51% increase per 10 years), living alone, occupations of trade and labourer, receipt of a government pension, hyperopia, and duration from the last eye examination, were associated with higher levels of undercorrected refractive error.

The association found with hyperopia (OR 1.45; 95% CI 1.15 to 1.83; p= 0.002) was stronger among subjects with the second criterion (three lines of improvement after refraction), (OR 1.79; 95% CI 1.27 to 2.51; p=0.0008) (data not shown). In contrast, no association was found between undercorrected refractive error and myopia (p=0.71). Longer duration from the last eye examination was associated with undercorrected refractive error (p for trend=0.001), which increased by 45% for each year.

Of the demographic variables, subjects with a past occupation of trade (OR 1.64; 95% CI 1.13 to 2.39; p=0.01) or labourer (OR 2.00; 95% CI 1.39 to 2.89; p=0.0002) were more likely to have undercorrected refractive error. Participants who lived alone (OR 1.34; 95% CI 1.05 to 1.72; p=0.02) and those who received a government pension (OR 1.47; 95% CI 1.12 to 1.94; p=0.006) were also more likely to have undercorrected refractive error.

Subjects who stated that they had worn distance glasses in the past were less likely to have undercorrected refractive error (OR 0.25; 95% CI 0.20 to 0.32; p=0.0001). Current drivers were also less likely to have undercorrected refractive error (OR 0.67; 95% CI 0.52 to 0.86; p=0.002). However, 56% of those who improved their visual acuity by two lines, and 54% of those who improved by at least three lines were still driving (88 subjects). Having higher education appeared to be inversely related although not quite statistically significant (OR 0.80; 95% CI 0.64 to 1.00; p=0.05).

Self reported visual symptoms, best corrected visual acuity, and presence of cataract, open angle glaucoma, or late stage ARM were not associated with undercorrected refractive error. Region of birth, language, current employment status, self reported health, presence of systemic illnesses, or use of community support services were also not significantly associated with undercorrected refractive error.

DISCUSSION
This study has found that undercorrected refractive error is a common condition in the older population, with almost a quarter improving by one line, around 10% by two lines, 5% by three lines, and around 2% by four or more lines on the logMAR chart. Almost one quarter of the people sampled in this cross sectional study had a visual acuity that could be improved by at least one line equivalent on the visual acuity chart, after refraction. Of those subjects presenting with a visual acuity of 6/9 or less, almost half (45.6%) were able to improve their vision by at least two lines (to 6/6 equivalent).

Age was strongly associated with undercorrected refractive error in this population, with a 51% increase found for each 10 year increase in age. This finding cannot be easily explained by an increased frailty or poorer general health of older people preventing attendance to an eye care practitioner. We found no increase in undercorrected refractive error among those who reported their general health as being only fair or poor, and among those who used community support services or were relatively dependent on others. We also found no association with common systemic illnesses.

Although a hyperopic refractive shift is known to occur with increasing age,[20 25–27] we found that after adjusting for age, hyperopic refraction was associated with an increased prevalence of undercorrected refractive error. Many older people with increasing hyperopia may not be aware that distance glasses could improve their vision. Alternatively, they may feel that they can see quite well without glasses or may resist wearing distance glasses, having not needed these in the past. This is supported by our finding that subjective perception of poor vision was not related to undercorrected refractive error, and that past wearing of distance glasses was negatively associated.

Lower socioeconomic status was found to predict undercorrected refractive error. Higher prevalence of undercorrected refractive error was found in those in receipt of a government pension, in people who stated their principal past occupation was tradesperson or labourer or in those with lower educational attainment. Taken together, these findings suggest that both perceived costs of attending an eye care practitioner and lack of knowledge of the potential benefits from refractive correction might inhibit many people from seeking assistance.

Participants who lived alone had higher prevalence of undercorrected refractive error, after adjusting for age, sex, and current driving status. Social isolation is known to result in a reduced attendance to health providers for many conditions, including visual impairment.

People still driving were less likely to have undercorrected refractive error. This suggests greater motivation by older drivers to maintain good distance vision in order to retain their driver's licence, or because they are more mobile and able to visit an eye care practitioner. Interestingly, those reporting having had a car accident while driving in the past year were not significantly more likely to have undercorrected refractive error. The small number of subjects in this subgroup (n=11), however, may have affected this finding. Around half of those with correctable refractive error of three or more lines were still driving, despite their vision being worse than 6/12, the statutory level for driving in all Australian states. Although reports have indicated that other measures of visual ability such as field of view may be more important in preventing automobile accidents,[28 29] this finding is of concern and has obvious legal implications. Given that driving ability is important for the independence of older people,[30] it indicates a need for targeted education of drivers regarding the benefits from regular eye examinations.

Few previous reports have examined factors associated with undercorrected refractive error, apart from the Melbourne Visual Impairment Project (MVIP).[17] Although the 10% prevalence of undercorrected refractive error reported by the MVIP was very similar to our rate of 10%, the MVIP report used a broader definition of this condition. The MVIP defined undercorrected refractive error as a one or more line improvement in those with presenting visual acuity worse than 6/6 (less two letters). In contrast, our study defined undercorrected refractive error by an improvement of at least two lines after refraction, in subjects with presenting visual acuity 6/9 or worse. We chose the criterion of two or more lines as we felt that this represented a clinically relevant level. A further difference between the studies was the inclusion in our comparison group of all remaining subjects, in order to more accurately represent the "normal" population, rather than only those with vision less than 6/6.

Despite these differences, relatively similar findings were made by these two studies. Both increasing age and time since eye examination were associated with undercorrected refractive error in the two studies, while past or current use of distance glasses was associated with a reduced prevalence of undercorrected refractive error. Language other than English spoken at home was a significant predictor in the MVIP but not in our study, reflecting the higher proportion of subjects from non-English speaking countries in the MVIP sample.

Our study has some limitations, including its cross sectional nature and the limited number of questions to define socioeconomic status. We did not ask about personal income as we felt that such questions could reduce participation. The strengths of our study include its high response and the detailed, standardised refraction performed on all participants.

In summary, this study has demonstrated that undercorrected refractive error is a common condition in the older population. Increasing age, hyperopia, social disadvantage, and isolation were found to be independently associated with a higher prevalence of this condition. Around half of those with correctable visual acuity worse than 6/12 were still driving. Undercorrected refractive error has been shown to have significant impacts on the independent living of older people and is readily and inexpensively corrected by provision of distance glasses. Knowledge of risk factors for undercorrected refractive error could assist in targeting education and appropriate referral by general practitioners and other primary care providers.

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