Single and Multiple Visual Function Impairments and Associated- Vision-Related Quality of Life Impact in Older Adults Aged 60 to 100 Years

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Purpose. Determine the prevalence and vision-related quality of life (VRQoL) effects of single and multiple visual function impairments (VFIs) in multi-ethnic older Asians.

Methods. A total of 2380 participants from a population-based cohort study were included. Visual function comprised presenting visual acuity (VA), contrast sensitivity (CS), depth perception (DP), and color vision (CV). Rasch-transformed VRQoL was obtained using the Brief Impact of Visual Impairment questionnaire. Multiple linear regression explored the independent (mutually adjusting for each VFI) impact of bilateral single (VAI, CSI, CVI and DPI) and multiple (i.e., the co-occurrence of any two, three, or four bilateral VFI) VFIs on VRQoL. Dominance analysis estimated the relative contribution for each of the single VFI on VRQoL.

Results. The prevalence of bilateral VAI, CSI, CVI, or DPI alone was 15.3%, 20.7%, 8.1%, and 23.5%, respectively, whereas for concurrent two, three and four bilateral VFIs was 11%, 4.1% and 1.6%, respectively. Participants with single bilateral VFI (except CVI) experienced poorer overall VRQoL (β −0.25 to −0.34; all $p < 0.05$) compared to those without. CSI had the largest contribution (25%), to the decline in overall VRQoL. As the number of concurrent bilateral VFIs increased, VRQoL progressively worsened (% decrements −12.26% to −25.61%; all $P < 0.001$) compared to no VFI.

Conclusions. Bilateral single and multiple VFIs are prevalent in older Asians. CSI had the largest contribution to VRQoL decrements. There was a systematic worsening in VRQoL scores with an increase in concurrent bilateral VFI. Comprehensive visual function testing may be warranted to prevent the debilitating consequences of VFIs on healthy aging.

Keywords: visual function, visual acuity, contrast sensitivity, color vision, depth perception, population-based, older adults, impact, vision-related quality of life

One of the challenges to healthy aging is visual impairment (VI),[1,2] which can be characterized by a decline in single or multiple visual function components, including visual acuity (VA), contrast sensitivity (CS), depth perception (DP), color vision (CV), and visual field (VF).[3] Although visual function deterioration in older adults is not driven by VA alone, most research has focused largely on the role of VA on vision-related QoL (VRQoL).[4–10] Research into the association between visual function components beyond VA and VRQoL has been limited to a handful of studies, and these have been largely in Caucasian populations. For example, The Salisbury Eye Evaluation study of 2520 U.S. elderly adults showed that individual VA, CS, glare, DP and VF were significant independent risk factors for self-reported visual disability.[11] Haymes and colleagues[12] also reported significant correlations between reduced CS ($r = 0.80$, $P < 0.001$) and VF ($r = 0.56$, $P < 0.001$) with difficulty performing activities of daily living.

Importantly, visual function deterioration in older adults rarely occurs in isolation, yet all existing studies have focused on single visual deficits.[11–14] Moreover, common ocular disorders usually affect more than one visual function to varying degrees. For instance, in early-stage glaucoma, diabetic retinopathy (DR), and AMD, CS is impaired before VA and VF.[15–17] Similarly, CV is affected in glaucoma, certain cataracts, and optic nerve head diseases more than VA.[18,19] In addition, ocular diseases often occur concurrently in older adults,[20] suggesting that multiple visual function impairment (VFIs) may be more prevalent and may have more detrimental impact than single component deficits. But, to date, there have been no studies evaluating the prevalence and impact of single and concurrent VFIs on VRQoL within a representative, community-dwelling, and multi-ethnic Asian population. This knowledge gap is of significant public interest as we aim to promote good visual health in older adults and align with a contem-

porary focus on healthy, independent, and meaningful aging.[21,22]

Against this background, we investigated the prevalence of single and multiple VFIs, comprising VA, CS, DP, and CV; the independent impact and contribution of the individual VFIs to VRQoL decline; and the independent association of multiple VFI with VRQoL, in a large cross-sectional population-based sample of Singaporean adults (Chinese, Malays, and Indians) aged ≥60 years. We hypothesize high prevalence rates of both single and multiple VFIs in elderly Singaporeans; and expect a decrease in VRQoL in subjects who have a single VFI as opposed to subjects having no VFI. Moreover, other VFIs, such as CS, will have an impact on VRQoL independent of VA. Additionally, we anticipate that as the number of VFIs increases, VRQoL will worsen.

Methods

Study Population

The Population Health and Eye Disease Profile in Elderly Singaporeans (PIONEER) is a population-based cohort study of community-dwelling older adults residing independently in Singapore, that aims to evaluate the epidemiology, patient-centered and economic impact of age-related sensory loss, together with its overarching relationship with systemic aging. The baseline visit was conducted between 2017 and 2022 among Chinese, Malay, and Indian adults aged ≥60 years living in Singapore. A detailed methodology is reported elsewhere.[23] In short, 6377 individuals were selected using an age-, sex-, and ethnicity-stratified sampling framework from a national database. Of these, 1015 (15.9%) were uncontactable, 648 (10.2%) were excluded because of being deceased, incarcerated, or residing in nursing homes/outside Singapore whereas 994 (15.6%) were ineligible because of being terminally ill, bedridden, or otherwise unable to give informed consent. Of the remaining 3720 (69.4%) eligible older adults, 2643 (71.1%) participated in the study, 1054 (28.3%) refused, and 23 (0.6%) were undecided (71.5% response rate). Compared to participants (n = 2643), non-participants (n = 1077) were older ($P < 0.001$) and more likely to be female ($P < 0.001$) and Chinese ($P < 0.001$; data not shown).

The study protocol followed the declaration of Helsinki and ethics approval from Singapore's centralized institutional review board was obtained before the study began recruitment (#2016/3089). Written consent was obtained from all participants.

Assessment of Visual Functions and Definition of VFIs

All participants underwent a comprehensive visual function examination, including VA, CS, DP, and CV, color fundus photography and clinical slit-lamp examination.

VA. Presenting distance VA was measured using a logarithm of the minimum angle of resolution (logMAR) number chart (Lighthouse International, Distance VA Number Chart, CAT No. C102) under photopic conditions (85 cd/m^2) at 4 m. Both presenting VA, ascertained with participants wearing habitual optical correction (if any), and best-corrected VA, in which refraction was corrected by trained and certified study optometrists, was obtained. If participants were unable to read the largest line of letters on the VA chart at 4 m, the chart was moved to 2 m. However, if they were still unable to make out any lines at 2 m, finger counting, hand movement and the ability of the eye to perceive light with a pen torch was assessed. Presenting VA in the better eye was used in the current study as VRQoL, the primary study outcome, reflects a participant's ability to perform visual tasks using their presenting vision.[24] VA impairment (VAI) was defined as bilateral presenting VA worse than 20/40 (>0.3 logMAR) in accordance with the 2019 World Health Organization criteria for VI.[25]

CS. The ability to recognize targets of different levels of contrast was measured using the Pelli-Robson Contrast Sensitivity Chart.[26] In brief, CS was measured with the participant's best refracted distance correction, corrected for the testing distance of 1 m with a 0.75D working distance lens under photopic condition. Scores range from 0.00 to 2.25 logCS with higher values indicating better CS. Bilateral contrast sensitivity impairment (CSI) was defined as CS < 1.55 logCS.[13,27]

DP/Stereopsis. The ability to see in three-dimensions was assessed using the Frisby Stereo test.[28] Participants were presented with a stereo image on a sequence of three transparent plates and were asked to identify the circle that has the depth cue in one of four squares for each of the three plates at 60 cm while wearing best refracted near correction. Scores range from 40–150 arc sec with lower values indicating better DP. DP impairment (DPI) was defined as stereo-acuity ≥150 arc sec.[29]

CV. CV was measured using the Farnsworth D-15 test. Participants were asked to arrange 15 different color discs in a sequential color series, monocularly, while wearing best corrected near correction. Bilateral CV impairment (CVI) was defined as one or more major crossings where the difference between two adjacent caps was more than three steps.[29]

VF. Data on VF were only available for a small subset of individuals diagnosed with glaucoma or glaucoma suspects; therefore our visual function comprised of only four visual components. However, we conducted sensitivity analyses including VF for prevalence of single bilateral VFI stratified by age, gender, and ethnicity in Supplementary Materials.

Multiple VFI was defined as the co-occurrence of impairments in any two, three, or four bilateral visual functions, respectively. Any VFI was defined as the presence of impairment in at least one (VAI, CVI, DPI or DPI) bilateral visual function.

Assessment of Vision-Related Quality of Life

To minimize potential biases and enhance comprehension, we ensured that all interviews, were administered in the preferred language of the participants, which included Chinese, Malay, Tamil, and various dialects by interviewers fluent in each. A standardized translation protocol was utilized to maintain consistency in terminology across different dialects.

VRQoL was assessed using the 15-item Brief Impact of Visual Impairment questionnaire (B-IVI; Supplementary Table S1).[30] The 15-item B-IVI comprises an overall score of VRQoL and two domain scores, namely visual functioning (e.g., "Needed help from other people because of your eyesight") and emotional well-being (e.g., "Lonely or isolated"). Rasch analysis using the Andrich rating scale model was conducted with Winsteps software (V.3.92; Chicago, IL, USA)[31,32] to examine the psychometric properties (e.g., response category ordering, measurement precision, item fit, unidimensionality, differential item functioning

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for age [≤70 years vs. >70 years] and gender, measurement range, and targeting) of the B-IVI and convert the raw scale scores to estimates of interval measures in log of the odds units (or logits) for parametric analysis. Higher scores indicate better VRQoL outcomes.

Assessment of Covariables and Associated Definitions

Self-reported information on sociodemographic characteristics (age, sex, ethnicity, income, education, and housing type), lifestyle factors (smoking status and frequency of alcohol consumption), medical history, and current medication were collected via an in-house questionnaire. Low socioeconomic status (SES) was defined as having primary or lower education and household monthly income < SGD$2000. Polypharmacy was considered present if the patient was taking 5 or more medications (excluding short-term medication, e.g., supplements; or vitamins).

Clinical covariates were obtained via a standardized clinical examination. Blood pressure (BP) was taken using a digital automatic BP monitor (Dinamap Pro Series DP110X-RW; GE Medical Systems Information Technologies, Inc, Livonia, MI, USA). Hypertension was defined as systolic BP ≥140mmHg, diastolic BP ≥90 mm Hg, self-reported use of antihypertensive medications, or self-reported history of physician-diagnosed hypertension.[33,34] Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared (Wt [kg]/Ht [m]^2). BMI was categorized as underweight (<18.5), normal (18.5 ≤ BMI < 23), overweight (BMI ≥23 to 27.5), and obese (BMI > 27.5) according to Asian cutoffs.[35]

Blood samples were collected for HbA1c, random glucose, and total, high-density lipoprotein, low-density lipoprotein cholesterol, and triglycerides measurements. Diabetes was defined as random glucose ≥11.1mmol/L, HbA1c ≥6.5%, self-reported use of diabetic medication or reported history of physician-diagnosed diabetes.[36] Dyslipidemia was defined as total cholesterol ≥5.2 mmol/L or low-density-lipoprotein cholesterol ≥3.4 mmol/L or triglycerides ≥1.7 mmol/L or self-reported use of lipid-lowering medications. Cardiovascular disease (CVD) was defined as self-reported history of myocardial infarction, angina, or stroke.[37] Chronic kidney disease (CKD) was defined as an estimated glomerular filtration rate <60 mL/min/1.73 m^2.[38]

After pupil dilation, fundus photographs were taken of each participant using a digital retinal camera (Canon CR-DGi with digital 10D SLR camera backing; Canon Inc., Tokyo, Japan) according to the Early Treatment for Diabetic Retinopathy Study guidelines. AMD was graded from retinal photographs by trained graders using the modified Wisconsin Age-Related Maculopathy Grading System.[39] In individuals with diabetes mellitus, DR was graded using the modified Airlie House classification system.[40,41] Glaucoma was defined using the International Society of Geographic and Epidemiological Ophthalmology scheme,[42] based on findings from gonioscopy, optic disc characteristics, and VF results. Cataract was graded using the Lens Opacities Classification System III.[43] Under-corrected refractive error was defined as the difference of at least 0.2 logMAR between presenting and best-corrected VA in either eye. All diagnoses were conducted by qualified ophthalmologists to ensure accuracy and reliability.

Statistical Analysis

Statistical evaluations were made using a two-sided test at the 5% significance level. All analyses were conducted using R version 4.3.1 (R Foundation for Statistical Computing, Vienna, Austria; URL: https://www.r-project.org/, accessed on August 21, 2023). Participant sociodemographic, lifestyle and clinical characteristics were summarized using means (SD) for continuous variables and counts (%) for categorical variables. Cramer's V was computed for all pairwise correlation among the VFI components. Because we oversampled minority ethnicities, female, and older participants, the overall, age, sex, and ethnicity-stratified prevalence rates for VFIs were determined by weighting individuals according to their sampling probabilities and standardizing to Singapore's 2020 population census.[44] The 95% confidence interval (CI) was computed using Korn-Graubard method.[45] As stated previously, sensitivity analyses using VF were performed and provided in Supplementary Results (Supplementary Table S3). Additionally, sensitivity analyses accounting for the COVID-19 period on the impact and contribution of single and multiple bilateral VFI on VRQoL was conducted (Supplementary Tables S4–Table S6).

We used multiple linear regression to investigate the associations between VFIs and overall VRQoL, visual functioning, and emotional well-being. To improve the comprehensiveness of our analysis, additional analyses treating VA and CS as continuous variables, are presented in Table 6. However, because testing for CV and DP use discrete measures, we were unable to carry out the same analyses for these two variables. The regression models were adjusted for confounders such as age, sex, ethnicity, and potential risk factors for VFI such as SES, loneliness, smoking status, alcohol consumption, BMI, polypharmacy, and presence of systemic comorbidities (diabetes, hypertension, dyslipidemia, CVD, CKD). Furthermore, to demonstrate an independent impact of different single VFI on VRQoL, in each of the single VFI models, we mutually adjusted for the other VFIs. To facilitate meaningful interpretation of the β coefficients, we calculated the percentage change (% change) in the model-adjusted marginal means of the VFI from the reference group. Regression coefficients were reported with 95% CI and considered statistically significant at a P value < 0.05. Furthermore, to estimate the relative contribution for each of the single VFI, we utilized dominance analysis to calculate the absolute effect (standardized beta [β]) contributed by each variable within the multivariable model against the sum of all absolute effects from these variables, expressed as a percentage.[46]

The minimal clinically important difference (MCID) was defined as the smallest reduction in the overall VRQoL score that participants perceived as detrimental.[47] The 0.5 SD difference was chosen as the threshold for clinical importance because it is an accepted criterion for the definition of the MCID, or the smallest change in outcome that an individual would identify as important, in QoL estimates.[48] This criterion has been shown to be consistent across various studies evaluating the MCID across a range of health conditions using both distribution-based (e.g., assessment of effect size) and anchor-based (e.g., differences between clinically defined groups) methodology.[49]

In this study, the cohort VRQoL MCID (0.63) was calculated as half of the standard deviation of participants' VRQoL scores through the distribution-based method.[47] To be considered clinically meaningful, VRQoL reductions

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needed to exhibit a β coefficient that equaled or surpassed the MCID.

Results

Psychometric Properties of the B-IVI

The overall B-IVI was found to have good range-based precision (person reliability coefficient 0.97), ordered thresholds, minimal evidence of multidimensionality, no differential item functioning, and good measurement range (Supplementary Table S2). One item displayed substantial misfit ("Lonely or isolated" infit MnSq 1.81), but it was retained because of its clinical importance. The Visual functioning and Emotional well-being domains also displayed good psychometric properties, despite one item from each displaying misfit (i.e., Visual functioning: "Needed help from other people because of your eyesight" infit MnSq 1.41; and Emotional well-being: "Lonely or isolated" infit MnSq 1.80). Because the item content was deemed important by the study team, both items were retained. Targeting was suboptimal for the overall B-IVI and the two subdomains (difference between person and item means >1.0 logits), reflecting the lack of VI in this population-based sample.

Participants' Characteristics

Of the 2643 enrolled study participants, two were <60 years old, five were of ethnicities other than Chinese, Malay, and Indian, and 256 had some components of visual function missing, leaving 2380 participants included for this cross-sectional investigation. Of the 2380 included participants, the mean age ± SD was 72.9 ± 8.3 years; 1198 (50.3%), 603 (25.3%) and 579 (24.3%) were of Chinese, Malay, and Indian ethnicities, respectively; and 1291 (54.2%) were female. A total of 1130 (47.5%) individuals had no VFI, whereas 1250 (52.5%) had any bilateral VFI (i.e., presence of at least one bilateral VFI). Compared to participants without VFI, those with VFI were older, Malay, more likely to live alone, had lower SES, and had poorer systemic (including higher prevalence of DM, hypertension, CVD and CKD), ocular, and VFI profiles (Table 1).

Table 2 displays the correlation matrix for the VFI components. The correlations observed between the different VFI components was generally weak, ranging from 0.130 between DPI and CVI to 0.286 between DPI and CSI. All pairwise correlations were statistically significant with $P <$ 0.001.

Prevalence of Bilateral Single VFI Stratified by Age, Gender and Ethnicity

The national census-adjusted prevalence of bilateral VAI, CSI, CVI, or DPI alone was 15.3% ($n = 432$), 20.7% ($n = 671$), 8.1% ($n = 257$), and 23.5% ($n = 721$), respectively. Moreover, the prevalence of bilateral VAI, CSI, CVI, and DPI increased with increasing age consistently (all P trend < 0.05), ranging from 6.1% to 46.5% (in 60–69 and ≥80 years, respectively), and this trend was consistent across sex and ethnic groups (Table 3). Overall, Malays were observed to have higher VFIs compared to Indians and Chinese; for example, the prevalence of CSI in Malays, Indians, and Chinese was 31.2%, 20.9% and 19.4%, respectively. There was little difference between the sexes. Additionally, census-adjusted prevalence of bilateral VAI, CSI, CVI, DPI or VF impairment was 14.1%, 17.7%, 5.7%, 22.1%, and 55.1%, respectively (Supplementary Table S3).

Prevalence of Bilateral Multiple VFIs Stratified by Age, Gender and Ethnicity

Population-census adjusted prevalence rates of two, three, or four bilateral VFIs were 10.8% (95% CI, 9.4%–12.3%), 4.1% (95% CI, 3.3%–5.0%) and 1.6% (95% CI, 1.1%–2.3%), respectively. Importantly, the prevalence of those with multiple VFIs (individuals with two to four bilateral VFIs) increased significantly with age (P trend < 0.001), ranging from 0.6% to 18.5% in those 60–69 and ≥80 years, respectively. In general, multiple VFIs were higher in Malay compared to Indian or Chinese individuals (e.g., the prevalence of any two-concomitant bilateral VFIs in Malays, Indians and Chinese were 15.7%, 11.8% and 10.1%, respectively), but there was little difference between sexes (Table 4). Additionally, 43.8% (95% CI, 41.3–46.3) of our sample had any bilateral VFI (data not shown).

Impact and Contribution of Single Bilateral VFI on VRQoL

In multivariate analysis using the proposed VFI thresholds to better differentiate the models (Table 5), those with bilateral VAI, CSI and DPI had statistically significant 8.4% ($\beta =$ −0.34; 95% CI, −0.54 to −0.14; $P < 0.001$), 8.3% ($\beta = -0.33$; 95% CI, −0.5 to −0.17; $P < 0.001$), and 6.3% ($\beta = -0.25$; 95% CI, −0.40 to −0.10; $P = 0.001$) reductions in the overall VRQoL, respectively, after controlling for other VFIs and confounders. Moreover, these decrements were significant for both visual functioning (7.67%, 6.5%, 6%, and 5% for VAI, CSI, CVI, and DPI, respectively; all $P < 0.05$) and emotional well-being (5.9%, 6%, and 6% for VAI, CSI and DPI, respectively; all $P < 0.05$) scores. When comparing the contribution of each of these VFIs to the decrements in overall VRQoL, the three largest contributors were CSI, VAI, and DPI, contributing from 15.0% to 24.9% of the adjusted $R^2 = 0.059$ within the final multivariable model. Similar results were observed for visual functioning (adjusted $R^2 = 0.070$) and emotional well-being (adjusted $R^2 = 0.037$) domains. Nonetheless, these VRQoL reductions were not clinically meaningful (Table 5). In sensitivity analyses (Supplementary Table S4), additionally accounting for COVID-19 period, we found no statistically significant differences in the impact and contribution of single bilateral VFI on overall and subscales of VRQoL.

Additionally, on analyzing VA and CS as continuous variables (Table 6), every unit increase in logMAR VA was associated with statistically significant reductions in the overall ($\beta = 0.84$; 95% CI, −1.29 to −0.39; $P < 0.001$), visual functioning $\beta = -0.73$; 95% CI, −1.05 to −0.41; $P < 0.001$) and emotional well-being ($\beta = -0.60$; 95% CI, −1.11 to −0.08; $P = 0.022$) scores of the B-IVI. Similarly, a per unit decrease in logCS was associated with statistically significant reductions in the overall ($\beta = -0.88$; 95% CI, −1.22 to −0.53; $P < 0.001$), visual functioning ($\beta = -0.61$; 95% CI, −0.85 to −0.36; $P < 0.001$), and emotional well-being ($\beta = -0.87$; 95% CI, −1.27 to −0.48; $P < 0.001$) scores of the B-IVI. When comparing the contribution of each of these VFIs to the decrements in overall VRQoL, the three largest contributors were CSI, VAI, and DPI, contributing from 11% to 32.5% of the adjusted R^2 value within the

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Table 1. Demographic, Systemic, and Socioeconomic Characteristics of the PIONEER Participants

Characteristics	No VFI ($N = 1130$)	Any VFI ($N = 1250$)	Overall ($N = 2380$)
Age (year), mean (SD)	70.1 (7.4)	75.4 (8.2)	72.9 (8.3)
Age group			
60–69	608 (53.8%)	333 (26.6%)	941 (39.5%)
70–79	352 (31.2%)	436 (34.9%)	788 (33.1%)
≥ 80	170 (15.0%)	481 (38.5%)	651 (27.4%)
Female gender	605 (53.5%)	686 (54.9%)	1291 (54.2%)
Ethnicity			
Chinese	605 (53.5%)	593 (47.4%)	1198 (50.3%)
Malay	253 (22.4%)	350 (28.0%)	603 (25.3%)
Indian	272 (24.1%)	307 (24.6%)	579 (24.3%)
Low SES (education and income), mean (SD)	135 (11.9)	244 (19.5)	379 (15.9)
Living alone, mean (SD)	86 (7.6)	125 (10.0)	211 (8.9)
Systemic conditions, mean (SD)			
Diabetes	365 (32.3)	440 (35.2)	805 (33.8)
Hypertension	920 (81.4)	1107 (88.6)	2027 (85.2)
Dyslipidemia	964 (85.3)	961 (76.9)	1925 (80.9)
CVD	179 (15.8)	223 (17.8)	402 (16.9)
CKD	142 (12.6)	300 (24.0)	442 (18.6)
BMI categories			
Underweight (BMI < 18.5)	46 (4.1)	68 (5.4)	114 (4.8)
Normal (BMI ≥ 18.5 and BMI < 23)	317 (28.1)	347 (27.8)	664 (27.9)
Overweight (BMI ≥ 23)	764 (67.6)	822 (65.8)	1586 (66.6)
Polypharmacy	203 (18.0)	271 (21.7)	474 (19.9)
Smoking			
Never smoked or past smoker	991 (87.7)	1084 (86.7)	2075 (87.2)
Current smoker	97 (8.6)	98 (7.8)	195 (8.2)
Alcohol frequency			
None	943 (83.5)	1051 (84.1)	1994 (83.8)
≤4 days per week	72 (6.4)	83 (6.6)	155 (6.5)
>4 days per week	32 (2.8)	24 (1.9)	56 (2.4)
Ocular diseases			
AMD	72 (6.4)	109 (8.7)	181 (7.6)
Cataract	672 (59.5)	984 (78.7)	1656 (69.6)
DR	84 (7.4)	115 (9.2)	199 (8.4)
Glaucoma	43 (3.8)	118 (9.4)	161 (6.8)
UCRE	320 (28.3)	499 (39.9)	819 (34.4)
Bilateral VFI measurements			
Presenting Visual Acuity (logMAR), mean (SD)	0.10 (0.09)	0.26 (0.20)	0.19 (0.18)
Range of logMAR			
Min	−0.20	−0.14	−0.20
Max	0.30	1.60	1.60
Contrast sensitivity (logCS), mean (SD)	1.79 (0.15)	1.54 (0.23)	1.66 (0.23)
Range of logCS			
Min	1.55	0.45	0.45
Max	1.98	1.95	1.98
Abnormal color vision, mean (SD)	0 (0)	257 (20.6)	257 (10.8)
Depth perception Impairment, mean (SD)	0 (0)	721 (57.7)	721 (30.3)
VRQoL overall, mean (SD)			
Raw score (out of 44)	43.2 (1.9)	42.3 (3.4)	42.8 (2.8)
Rasch score	4.8 (1.0)	4.4 (1.4)	4.6 (1.3)
VRQoL–Visual Functioning, mean (SD)			
Raw score (out of 26)	25.7 (1.0)	25.2 (2.0)	25.5 (1.6)
Rasch score	4.2 (0.7)	3.9 (1.1)	4.1 (0.9)
VRQoL–Emotional well-being, mean (SD)			
Raw score (out of 18)	17.5 (1.3)	17.0 (1.8)	17.3 (1.6)
Rasch score	5.6 (1.2)	5.2 (1.6)	5.4 (1.4)

UCRE, undercorrected refractive error.

final multivariable model. Similar results were observed for visual functioning and emotional well-being domains. Nonetheless, these VRQoL reductions were not clinically meaningful (Table 6). Sensitivity analyses (accounting for COVID-19 period) revealed similar findings (Supplementary Table S5).

Impact of Bilateral Multiple VFI on VRQoL

Table 7 shows the results of multivariable adjusted associations between multiple VFIs with VRQoL. As the number of concurrent bilateral VFIs increased, overall VRQoL progressively worsened including visual functioning and emotional

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Table 2. Correlation Matrix Among VFI Components

	VAI	CSI	CVI	DPI
VAI	1			
CSI	0.282	1		
CVI	0.194	0.167	1	
DPI	0.221	0.286	0.130	1

Cramer's V is computed for all pairwise correlation. All pairwise correlations are significant at $P < 0.001$.

well-being (all P trend < 0.001). Individuals with four bilateral VFIs had the worst VRQoL (25.6%, 21.7%, and 18.5% reduction for overall, visual functioning and emotional well-being, respectively; all $P < 0.001$) compared to no VFI. Importantly, only those with three or four bilateral VFIs experienced clinically meaningful VRQoL (overall, visual functioning, and emotional well-being) reductions. On further adjusting for COVID-19 period as a potential confounder of VFI, in sensitivity analyses (Supplementary Table S6), no significant differences on the impact of multiple VFI on VRQoL and subtypes was observed.

Discussion

In our large, contemporary, population-based multiethnic study, approximately 15.3%, 20.7%, 8.8%, and 23.5% of older Singaporeans had bilateral single VAI, CSI, CVI, and DPI, respectively. Almost one fifth had multiple bilateral VFIs, of which 11%, 4.2% and 1.6% had two, three, and four bilateral VFIs, respectively. We found that older adults affected by bilateral single VFI experienced a significant decline in VRQoL and subscales when compared to those with no VFI. Interestingly, CSI had the largest contribution to VRQoL decline across all domains. Moreover, as the number of concurrent bilateral VFIs increased, VRQoL and subscales progressively worsened. Given the recent focus on healthy and meaningful aging, our data suggest the need for comprehensive visual function screenings particularly CS and DP assessment in addition to VA alone. Furthermore, it underscores the critical importance of early visual rehabilitation in this demographic to curb VRQoL decline.

Our findings reveal significant decreases in overall VRQoL, visual functioning and emotional well-being among our study participants with a single VFI, except for CVI. Importantly the magnitude of deficit in VRQoL was the largest for CSI followed by DPI and VAI. This underscores the critical importance of CS measurements as a key factor influencing VRQoL and highlights the need to prioritize CS in both clinical assessments and interventions to preserve or enhance VRQoL. Moreover, among those with *only* bilateral single VFI ($n = 692$ [27.6%]), ~22% had visual function deficits that did not include VAI (10.7%, 8%, and 3.4% had DPI alone, CSI alone, and CVI alone—mutually exclusive categories). Collectively, these results suggest for a pressing need to test beyond VA, especially in resource-rich areas; comprehensive visual function screening should be promoted whereas CS, DP, and VA screening may be focused on in resource-poor areas.

Our study's findings of a 15.3% prevalence of bilateral VI overall and 10.5% in individuals aged 60–69 years are different from those in other countries. For example, Flaxman and colleagues[50] reported that less than 5% of adults aged 65–69 years in the United States had bilateral VI, defined as BCVA <20/40 in the better-seeing eye. This discrepancy may arise from several factors, including the different definitions of VI used (BCVA in the U.S. study vs. PVA in our study), variations in participant characteristics, and disparities in access to healthcare facilities across countries. However, our prevalence of bilateral VI is consistent with epidemiological data from Singapore. For instance, the Singapore Chinese Eye Disease Study (SCES; 2009–2011) reported an age-standardized prevalence of 17.7% overall and 23.4% for those aged 60–69 years for bilateral VI, defined as VA <20/40 to ≥20/200 in the better-seeing eye.[51] The slightly lower prevalence observed in our study compared to SCES may reflect improvements in awareness of eye health and diseases, as well as increased accessibility to and use of eye care services across Singapore in recent years.

Similar to our results, studies in Caucasian adults have shown that reduction in individual visual measures such as CS, DP, and VF is independently (after mutually adjusting for each of the visual measures studied) associated with increased odds of self-reported visual disability including difficulty in distance vision, near vision and driving.[11] Similarly, West and associates[14] demonstrated an independent contribution of poor CS to deficits in performance of everyday tasks that required vision. In a recent study by Flaharty and colleagues,[52] a one-line reduction in better eye CS had more adverse impact on VRQoL than a two-line decrease in VA, demonstrating the importance of CS in people's visual function and QoL, pointing toward a comprehensive visual function assessment than VA alone.

Because ours is the first population-based study in older adults to report the prevalence of single *and* multiple VFIs, it is difficult to compare results pertaining to such combinations to existing literature. Likewise, to date, no study has explored the impact of multiple VFIs on VRQoL. In the current study, we have comprehensively explored the effect of multiple bilateral VFIs on composite VRQoL and subscales and found that as the number of bilateral VFIs increased, progressively greater reductions in overall VRQoL, as well as visual functioning and emotional well-being, were observed. These findings underscore the importance of a comprehensive approach that focuses on optimizing both visual outcomes (e.g., interventions targeted at *specific* VFI such as for depth and contrast issues vs. a simple magnifier), and overall well-being (e.g., through interventions like cognitive-behavioral therapy, problem-solving therapy, and multidisciplinary care).[53,54] Future studies are needed to corroborate our findings and elicit a better understanding of the cumulative impact of multiple VFIs.

Moreover, weak correlations among the VFI components indicate that each component measures different aspects of visual function rather than overlapping. This further reinforces the importance of a thorough visual function evaluation to capture the full range of visual impairments. Taken together, our findings indicate that measuring standard VA alone is insufficient to understand the visual world of older adults, particularly given that the aging population will likely present with multiple visual disorders clinically as age-related pathophysiological processes such as oxidative stress and endothelial dysfunction that disrupt the structure and function of the eyes and optic nerves may afflict multiple visual functions.[55] Therefore comprehensive visual function screening is necessary for this group.

Strengths of our study include a large, well-characterized and geographically representative study sample; the availability of high-quality objectively assessed visual functions, ocular and systemic data; and comprehensive multivariable

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Table 3. Prevalence of Single Bilateral VFI Stratified by Age, Gender, and Ethnicity in the PIONEER Study

			Gender				Ethnicity					
	All ($N = 2380$)		Male ($N = 1089$)		Female ($N = 1291$)		Chinese ($N = 1198$)		Malay ($N = 603$)		Indian ($N = 579$)	
	N	Weighted, % (95% CI)	*N*	Weighted, % (95% CI)	*n*	Weighted, % (95% CI)	*n*	Weighted, % (95% CI)	*n*	Weighted, % (95% CI)	*n*	Weighted, % (95% CI)
Bilateral VAI												
60–69	100	10.5% (8.2, 13.1)	40	9.2 (6.2, 13.0)	60	11.7 (8.3, 15.7)	45	10.4 (7.7, 13.7)	29	10.4 (7.1, 14.7)	26	11.0 (7.3, 15.6)
70–79	140	17.5 (14.4, 20.8)	51	14.1 (9.9, 19.1)	89	20.4 (16.1, 25.2)	74	17.3 (13.8, 21.2)	37	20.4 (14.8, 27.1)	29	15.9 (10.9, 22.2)
≥80	192	30.9 (26.1, 36.0)	74	25.9 (20.0, 32.5)	118	34.0 (27.1, 41.3)	103	30.8 (25.4, 36.7)	51	36.4 (27.6, 45.9)	38	23.7 (17.2, 31.3)
P trend		<0.001		<0.001		<0.001		<0.001		<0.001		0.002
Total	432	15.3 (13.6, 17.2)	165	12.5 (10.2, 15.1)	267	17.8 (15.3, 20.6)	222	15.4 (13.4, 17.6)	117	15.6 (12.8, 18.7)	93	13.8 (11.0, 17.0)
Bilateral CSI												
60–69	143	11.5 (9.3, 14.1)	63	12.0 (8.7, 16.0)	80	11.1 (8.1, 14.7)	41	9.5 (6.9, 12.6)	69	24.3 (19.4, 29.7)	33	14.4 (10.1, 19.6)
70–79	225	26.4 (22.9, 30.2)	80	21.3 (16.3, 27.0)	145	30.9 (25.9, 36.3)	109	25.4 (21.4, 29.8)	65	35.8 (28.8, 43.2)	51	27.5 (21.2, 34.6)
≥80	303	46.5 (41.3, 51.7)	114	35.5 (29.1, 42.4)	189	53.4 (45.9, 60.7)	146	45.3 (39.4, 51.3)	89	64.2 (55.0, 72.7)	68	40.7 (32.9, 48.9)
P trend		<0.001		<0.001		<0.001		<0.001		<0.001		<0.001
Total	671	20.7 (18.9, 22.6)	257	17.3 (14.7, 20.2)	414	23.7 (21.2, 26.4)	296	19.4 (17.3, 21.6)	223	31.2 (27.5, 35.2)	152	20.9 (17.6, 24.6)
Bilateral CVI												
60–69	60	6.1 (4.4, 8.3)	36	8.2 (5.4, 11.9)	24	4.0 (2.2, 6.7)	26	6.0 (4.0, 8.6)	16	5.9 (3.4, 9.4)	18	7.9 (4.7, 12.2)
70–79	72	8.2 (6.1, 10.7)	37	8.9 (5.7, 13.2)	35	7.5 (4.9, 11.0)	33	7.8 (5.4, 10.8)	15	8.1 (4.6, 13.0)	24	13.5 (8.8, 19.5)
≥80	125	16.2 (12.5, 20.4)	53	17.0 (12.1, 22.9)	72	15.7 (10.7, 21.8)	49	15.1 (11.0, 19.9)	27	19.4 (12.7, 27.8)	49	29.5 (22.4, 37.4)
P trend		<0.001		<0.001		<0.001		<0.001		<0.001		<0.001
Total	257	8.1 (6.8, 9.6)	126	9.4 (7.3, 11.9)	131	6.9 (5.4, 8.8)	108	7.8 (6.3, 9.6)	58	7.8 (5.8, 10.4)	91	11.9 (9.3, 14.9)
DPI												
60–69	167	15.1 (12.5, 18.0)	96	19.3 (15.2, 24.1)	71	11.0 (7.9, 14.8)	59	13.6 (10.5, 17.2)	63	22.8 (17.9, 28.2)	45	20.0 (15.0, 25.8)
70–79	255	30.6 (26.8, 34.6)	123	32.3 (26.5, 38.6)	132	29.1 (24.2, 34.4)	125	29.6 (25.3, 34.3)	72	39.1 (31.9, 46.5)	58	32.3 (25.5, 39.7)
≥80	299	43.1 (38.0, 48.4)	149	46.0 (39.1, 53.1)	150	41.3 (34.2, 48.7)	147	41.8 (36.0, 47.8)	77	55.6 (46.1, 64.7)	75	46.5 (38.6, 54.4)
P trend		<0.001		<0.001		<0.001		<0.001		<0.001		<0.001
Total	721	23.5 (21.5, 25.6)	368	26.1 (22.9, 29.4)	353	21.2 (18.7, 23.9)	331	22.5 (20.1, 24.9)	212	30.2 (26.4, 34.2)	178	26.3 (22.6, 30.4)

Weighted prevalences were calculated with sampling weights specific to each age group, gender and ethnicity to adjust for oversampling and post-stratification weights to align to the population distribution based on the 2020 Singapore Census. *P* trend will not be computed for counts less than 5 in any age group or if the total count is less than 20.

Table 4. Prevalence of Multiple Bilateral VFI Stratified by Age, Gender and Ethnicity in the PIONEER Study

			Gender				Ethnicity					
	All ($N = 2380$)		Male ($N = 1089$)		Female ($N = 1291$)		Chinese ($N = 1198$)		Malay ($N = 603$)		Indian ($N = 579$)	
	N	Weighted, % (95% CI)	*n*	Weighted, % (95% CI)	*n*	Weighted, % (95% CI)	*n*	Weighted, % (95% CI)	*n*	Weighted, % (95% CI)	*n*	Weighted, % (95% CI)
Any 2 Bilateral VFI												
60–69	74	5.8 (4.2, 7.7)	36	6.8 (4.4, 10.1)	38	4.8 (2.9, 7.3)	20	4.6 (2.8, 7.0)	36	12.8 (9.1, 17.3)	18	7.9 (4.7, 12.2)
70–79	132	16.8 (13.8, 20.2)	60	16.1 (11.7, 21.3)	72	17.5 (13.4, 22.2)	72	16.9 (13.5, 20.8)	32	17.1 (12.0, 23.2)	28	15.2 (10.3, 21.3)
≥80	142	18.5 (14.8, 22.7)	67	20.4 (15.2, 26.5)	75	17.3 (12.4, 23.2)	60	17.0 (12.9, 21.8)	41	30.8 (22.6, 40.2)	41	24.8 (18.2, 32.4)
P trend		<0.001		<0.001		<0.001		<0.001		<0.001		<0.001
Total	348	10.8 (9.4, 12.3)	163	11.0 (8.9, 13.4)	185	10.5 (8.7, 12.6)	152	10.1 (8.5, 11.9)	109	15.7 (12.8, 19.0)	87	11.8 (9.2, 14.8)
Any 3 Bilateral VFI												
60–69	15	1.3 (0.6, 2.5)	8	1.5 (0.5, 3.5)	7	1.1 (0.3, 2.8)	5	1.2 (0.4, 2.7)	7	2.5 (1.0, 5.1)	3	1.3 (0.3, 3.9)
70–79	47	5.2 (3.6, 7.3)	12	3.0 (1.2, 5.9)	35	7.1 (4.6, 10.4)	21	4.8 (3.0, 7.3)	15	8.4 (4.8, 13.4)	11	5.9 (3.0, 10.3)
≥80	94	13.2 (10.0, 16.9)	37	11.5 (7.5, 16.6)	57	14.2 (9.8, 19.7)	47	12.9 (9.3, 17.2)	25	16.6 (10.6, 24.2)	22	12.9 (8.1, 19.2)
P trend		<0.001		<0.001		<0.001		<0.001		<0.001		—
Total	156	4.1 (3.3, 5.0)	57	3.1 (2.1, 4.4)	99	5.0 (3.8, 6.4)	73	3.9 (3.0, 5.1)	47	5.4 (3.8, 7.4)	36	3.9 (2.6, 5.6)
All 4 Bilateral VFI												
60–69	11	1.0 (0.4, 2.1)	6	1.4 (0.4, 3.4)	5	0.6 (0.1, 2.0)	4	0.9 (0.3, 2.3)	3	1.1 (0.2, 3.3)	4	1.7 (0.5, 4.3)
70–79	10	0.6 (0.2, 1.3)	7	1.0 (0.2, 2.6)	3	0.2 (0.0, 0.7)	1	0.3 (0.0, 1.4)	4	2.2 (0.6, 5.5)	5	2.9 (1.0, 6.7)
≥80	36	6.5 (3.9, 9.9)	12	4.4 (2.0, 8.3)	24	7.7 (4.0, 13.1)	17	6.3 (3.5, 10.4)	12	8.8 (4.3, 15.7)	7	5.0 (2.0, 10.2)
P trend		<0.001		0.021		—		—		—		—
Total	57	1.6 (1.1, 2.3)	25	1.6 (0.8, 2.8)	32	1.6 (0.9, 2.7)	22	1.5 (0.9, 2.4)	19	2.2 (1.2, 3.6)	16	2.4 (1.3, 4.1)

Weighted prevalences were calculated with sampling weights specific to each age group, gender and ethnicity to adjust for oversampling and post-stratification weights to align to the population distribution based on the 2020 Singapore Census. *P* trend will not be computed for counts less than 5 in any age group or if the total count is less than 20.

Table 5. Multivariable Impact and Contribution of Single Bilateral VFI on VRQoL

Exposure: Single VFI	β Coefficient* (95% CI)	*P* Value	% Change	Standardized Dominance Statistic†
Outcome: VRQoL overall				
VAI				
No	Reference	NA	NA	
Yes	−0.34 (−0.54, −0.14)	<0.001	−8.43	17.6
CSI				
No	Reference	NA	NA	
Yes	−0.33 (−0.50, −0.17)	<0.001	−8.28	24.9
CVI				
No	Reference	NA	NA	
Yes	−0.20 (−0.43, 0.04)	0.100	−4.93	4.1
DPI				
No	Reference	NA	NA	
Yes	−0.25 (−0.40, −0.10)	0.001	−6.27	15.0
Outcome: Visual Functioning				
VAI				
No	Reference	NA	NA	
Yes	−0.28 (−0.42, −0.13)	<0.001	−7.69	20.4
CSI				
No	Reference	NA	NA	
Yes	−0.23 (−0.35, −0.12)	<0.001	−6.55	24.0
CVI				
No	Reference	NA	NA	
Yes	−0.21 (−0.38, −0.04)	0.013	−5.94	7.6
DPI				
No	Reference	NA	NA	
Yes	−0.17 (−0.28, −0.07)	0.002	−4.94	15.1
Outcome: Emotional Well-being				
VAI				
No	Reference	NA	NA	
Yes	−0.29 (−0.52, −0.07)	0.012	−5.83	13.5
CSI				
No	Reference	NA	NA	
Yes	−0.30 (−0.49, −0.12)	0.002	−6.03	20.9
CVI				
No	Reference	NA	NA	
Yes	−0.05 (−0.32, 0.21)	0.711	−1.03	0.8
DPI				
No	Reference	NA	NA	
Yes	−0.30 (−0.48, −0.13)	<0.001	−6.07	18.4

Minimal clinically important difference (defined as 0.5 SD of baseline VRQo) = 0.63. All models were adjusted for age, gender, ethnicity, socioeconomic status, living alone, smoking status, alcohol frequency, body mass index, diabetes, hypertension, dyslipidemia, CVD, CKD, and polypharmacy. Furthermore, each of the single VFI models was mutually adjusted for the other VFIs. Adjusted R^2 values of the models with overall, visual functioning and emotional well-being scores of VRQoL are 0.0593, 0.0703, and 0.0376, respectively.

* Coefficients derived from linear regression models.

† Standardized dominance statistics are expressed in percentages

adjustments for a range of relevant confounders. Moreover, we applied Rasch analysis to our B-IVI data to ensure psychometric properties of the scale were adequate and to transform raw scores to interval level estimates which increases measurement precision in parametric analyses.[56] Although fit to the Rasch model was good overall, we observed item misfit for one item each in the Visual Functioning and Emotional well-being domains, which may have distorted measurement to some extent. However, the study team opted to retain these items because their content was deemed to be important.[57]

There are also some limitations. Data on VF were only available for a small subset of individuals diagnosed with glaucoma or glaucoma suspects and, hence, are not generalizable to the entire population, thereby leading to selection bias (Supplementary Table S3). Therefore, in this study we have restricted our analyses to the four VFIs. In addition to examining the number of VFIs, we explored which combinations of VFI types might have a greater impact on VRQoL by analyzing interaction terms to assess whether there were risks beyond the expected cumulative effect of having two, three, or four VFIs. However, none of the interaction terms was found to be significant. Further studies, incorporating data on combinations of VFI types, severity of VFIs, and VF, are needed to gain a deeper understanding of the full impact of VFIs. Unlike VA, there are no established clinical standards for defining other visual function parameters like CS, DP, and CV, which are not routinely evaluated in clinics. To align with previous studies, we used cutoffs from these publications,[13,29] but future studies should establish standardized protocols for greater precision and clinical relevance. Our low adjusted R^2 values in Tables 5 and 6 suggest that overall QoL may be influenced by factors beyond those included in our study such as coping, access to eye care, and illness

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Table 6. Multivariable Impact and Contribution of Single Bilateral VFI on VRQoL (With VA and CS as Continuous Variables)

VFI	β Coefficient* (95% CI)	*P* Value	% Change	Standardized Dominance Statistic†
Outcome: VRQoL overall				
Presenting Visual Acuity (per unit increase in logMAR)	−0.84 (−1.29, −0.39)	<0.001	NA	21.1
Contrast Sensitivity (per unit decrease in logCS)	−0.88 (−1.22, −0.53)	<0.001	NA	32.5
CVI				
No	Reference	NA	NA	
Yes	−0.16 (−0.39, 0.08)	0.185	−3.74	3.0
DPI				
No	Reference	NA	NA	
Yes	−0.21 (−0.36, −0.06)	0.008	−4.91	11.0
Outcome: Visual Functioning				
Presenting Visual Acuity (per unit increase in logMAR)	−0.73 (−1.05, −0.41)	<0.001	NA	25.7
Contrast Sensitivity (per unit decrease in logCS)	−0.61 (−0.85, −0.36)	<0.001	NA	31.8
CVI				
No	Reference	NA	NA	
Yes	−0.18 (−0.35, −0.01)	0.035	−4.78	5.5
DPI				
No	Reference	NA	NA	
Yes	−0.14 (−0.25, −0.03)	0.012	−3.76	11.0
Outcome: Emotional Well-being				
Presenting Visual Acuity (per unit increase in logMAR)	−0.60 (−1.11, −0.08)	0.022	NA	15.1
Contrast Sensitivity (per unit decrease in logCS)	−0.87 (−1.27, −0.48)	<0.001	NA	31.0
CVI				
No	Reference	NA	NA	
Yes	−0.02 (−0.28, 0.24)	0.881	−0.40	0.6
DPI				
No	Reference	NA	NA	
Yes	−0.27 (−0.44, −0.09)	0.003	−5.13	13.8

Minimal clinically important difference (defined as 0.5 SD of baseline VRQoL) = 0.63. All models were adjusted for age, gender, ethnicity, socioeconomic status, living alone, smoking status, alcohol frequency, BMI, diabetes, hypertension, dyslipidemia, CVD, CKD and polypharmacy. Furthermore, each of the single VFI models was mutually adjusted for the other VFIs. Adjusted R^2 values of the models with overall, visual functioning and emotional well-being scores of VRQoL are 0.0719, 0.0855 and 0.0459, respectively.

* Coefficients derived from linear regression models.

† Standardized dominance statistics are expressed in percentages

Table 7. Multivariable Associations Between Number of Bilateral VFI and VRQoL

Exposure: Number of VFI	β Coefficient* (95% CI)	*P* Value†	% Change
Outcome: Visual Functioning			
No VFI	Reference	NA	NA
Single Bilateral VFI	−0.38 (−0.53, −0.23)	<0.001	−8.51
2 bilateral VFI	−0.55 (−0.75, −0.34)	<0.001	−12.26
3 bilateral VFI	−0.87 (−1.19, −0.55)	<0.001	−19.45
4 bilateral VFI	−1.14 (−1.69, −0.59)	<0.001	−25.61
Outcome: Visual Functioning			
No VFI	Reference	NA	NA
Single Bilateral VFI	−0.25 (−0.36, −0.14)	<0.001	−6.49
2 bilateral VFI	−0.41 (−0.56, −0.26)	<0.001	−10.44
3 bilateral VFI	−0.71 (−0.95, −0.48)	<0.001	−18.32
4 bilateral VFI	−0.84 (−1.24, −0.45)	<0.001	−21.63
Outcome: Emotional Well-being			
No VFI	Reference	NA	NA
Single Bilateral VFI	−0.34 (−0.51, −0.17)	<0.001	−6.35
2 bilateral VFI	−0.53 (−0.77, −0.30)	<0.001	−9.93
3 bilateral VFI	−0.78 (−1.15, −0.42)	<0.001	−14.58
4 bilateral VFI	−0.99 (−1.62, −0.36)	0.002	−18.48

Minimal clinically important difference (defined as 0.5 SD of baseline VRQoL) = 0.63. All models were adjusted for age, gender, ethnicity, socioeconomic status, living alone, smoking status, alcohol frequency, BMI, diabetes, hypertension, dyslipidemia, CVD, CKD and polypharmacy. Furthermore, each of the single VFI models was mutually adjusted for the other VFIs. Adjusted R^2 values of the models with overall, visual functioning and emotional well-being scores of VRQoL are 0.0598, 0.0702 and 0.0362, respectively.

* Coefficients derived from linear regression models.

† Overall *P* trend for VRQoL overall, VF and EMO scores are <0.001.

perception. Future research should explore these additional variables for a more comprehensive understanding of VFIs impact on QoL. The weak correlation observed between CS and VA compared to other clinical studies[58–60] may reflect the predominance of participants with normal vision or mild vision loss in our population-based study. Nonetheless, our findings remain important for demonstrating the significant contribution of CS to VRQoL at a population-based level. In our study population, we observed a ceiling effect for the B-IVI, which is unsurprising given that the B-IVI was originally validated in an Australian cohort. This effect may be attributable to cultural differences between the validation group and our study participants. Despite this, the other psychometric indices of the B-IVI were satisfactory, suggesting that the ceiling effect did not compromise its overall appropriateness. Nonetheless, these findings should be interpreted with some caution. Last, our cross-sectional data prevent cause-effect inferences. Longitudinal studies, such as the ongoing PIONEER-2, will help confirm the temporality and mechanisms of these findings over time.

In conclusion, our study found that 15.3%, 20.7%, 8.8%, and 23.5% of community-dwelling Singaporean aged 60 years and older had bilateral VAI, CSI, CVI, and DPI, respectively. Nearly one fifth of the population had multiple bilateral VFIs. Compared to individuals without VFI, those with a single bilateral VFI demonstrated substantially poorer VRQoL, affecting both visual functioning and emotional well-being, with CSI contributing to the largest decline. Furthermore, individuals who had a greater number of concurrent bilateral VFIs reported significantly worse VRQoL and subscales compared to those without VFI. These findings highlight the importance of comprehensive visual function screening particularly CS and DP assessment in addition to standard VA, to address the marked VRQoL decline in this growing older population.

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