Title:

Visual function assessment of diagnostic radiography students

Manuscript type:

Original full length research paper

Authors:

Lockwood, P[1]. Blackman, A[1,2].

Affiliations:

[1]Medical and Clinical Sciences Research Hub, School of Allied Health Professions, [1]Canterbury Christ Church University, Kent, ME4 4UF, UK

[2]The Association of British Dispensing Opticians College, Godmersham Park, Godmersham, Canterbury, Kent CT4 7DT

Corresponding author

Paul Lockwood (paul.lockwood@canterbury.ac.uk)

Present address:

Clinical and Medical Sciences Research Hub, School of Allied Health Professions, Canterbury Christ Church University, Kent, UK

Abstract

Introduction: Deterioration of visual acuity (VA) and visual impairment has been linked to age-related subtle changes, gender, and a correlation to socioeconomic status. This study aimed to assess first-year diagnostic radiography students' visual functional abilities by applying the International Classification of Impairments, Disabilities and Handicaps (ICIDH) recommendations of functional VA screening and health-related quality of life questionnaire (HRQOL)

Methods: The design followed the World Health Organisation (WHO) electronic VA testing of monocular sight using LogMAR charts and binocular vision using Snellen charts, and an HRQOL questionnaire assessing for reduced ability of visual-based tasks in activities of daily living (ADL). The data was evaluated in correlation to the participant's visual correction, age, gender, and socioeconomic background.

Results: Seventy students were recruited, all meeting the WHO standard level for visual ability, with 100% (n=70/70) met or achieved above normal binocular vision, correlating to expected normal population results from published studies for age. The monocular vision demonstrated 74% (n=52/70) for the right eye, and 80% (n=56/70) for the left eye for normal vision levels. The results did not differ significantly between each eye (p=0.21), gender variations between the left eye (p=0.27) and the right eye (p=0.10) results were affected by sample ratio of females (80%; n=56/70) to males (20%; n=14/70), the visual correction did not impair binocular VA. The HRQOL assessment indicated no significant functional VA issues in the study sample. The study demonstrated no association between the participant's socioeconomic background that may influence their VA ability.

Conclusion: The results provided normative binocular and monocular data on visual function in a sample of student radiographers and indicated that their thresholds align to normal (or near-normal) VA standards.

Implications for practice: The visual health data was reviewed for subgroup comparison and trend analysis, and did not identify risk factors within this sample group that their VA and visual functioning would impact upon radiography clinical placement tasks and activities. The sample is not generalisable to the wider population; further studies are recommended.

Introduction

The role of the diagnostic radiographer in clinical practice combines multiple complex activities of image acquisition, image processing and image interpretation. These tasks can be deemed visually demanding, requiring good visual acuity (VA) and necessitating a prolonged focus on computer screens. Visual abnormalities in human vision are common in the general population, and often involve conditions such as colour blindness[1-3] to stereoblindness.[4-6] Additionally, studies have noted deterioration of VA and visual impairment has been linked to age-related subtle changes,[7-10] a predisposition to females,[10] and a correlation to lower socioeconomic status.[11] Prolonged image reading tasks may exaggerate known ocular symptoms or increase the chance of fatigue of the ciliary and extraocular muscles resulting in eye strain (aesthenopia)[12-14] or temporary myopia.[15] The consequences of reduced VA when acquiring, processing and commenting upon (red dot or preliminary clinical evaluation) of medical imaging may result in errors which could potentially impact patient management decisions.[16]

Within the United Kingdom (UK), admissions requirements for undergraduate diagnostic radiography programmes at higher education institutes (HEI's) require applications through the Universities and Colleges Admissions Service (UCAS). The 2018-19 applications are set on the academic ability of between 104–120 UCAS tariff points (incorporating the Scottish tariff, Welsh/European Baccalaureate Diploma tariff, and Irish Leaving Certificate).[17] With occupational health screening for medical conditions (excluding VA screening) and vaccination history to risk assess for clinical placement. Enhanced disclosure and barring background check for working with vulnerable children and adults is further required by UK law.[18,19] The HEI Interview scenarios for applicants are based on the National Health Service (NHS) values-based recruitment approach[20-25] assessing individual values and behaviors that align with the principles of the NHS constitution.[20,24,25] Furthermore, some HEI's conduct entrance tests in English and Math's, spatial processing, situational judgement, communication and team working (such as the Health Professions Admission Test).[26,27]

Many UK occupations include recruitment screening for visual fitness to work as recommended by guidelines from the Royal College of Ophthalmologists (RCOphth) [28] and enforced by the UK Health and Safety Executive, although Radiography is not listed. Within the field of medical imaging, one could equally contest that there might be a requirement for occupational visual screening[29] for student radiographers to operate at a safe level in clinical practice.

This study aimed to assess first-year diagnostic radiography students visual functional abilities, by applying the International Classification of Impairments, Disabilities and Handicaps (ICIDH)[30] recommendations of functional VA screening with a health-related quality of life questionnaire (HRQOL) to assess for reduced ability of visual-based tasks in activities of daily living (ADL).[30,31]

Method

Institutional ethics approval was received (Ref:1/H&W/02C), and all participants gave written informed consent to participate. The student cohort size was 80 students, none of the candidates were on medication at the time of the study. Participants were advised for the VA tests to wear visual correction (glasses or contact lenses) if they normally used them for daily visual tasks.

The first stage assessment of visual tasks and socioemotional functioning (ADL) used the National Eye Institute (NEI) Visual Function Questionnaire (VFQ-25).[32,33] The VFQ-25 is a validated repeated measures design and reliable scale of the participants' HRQOL, containing 25 visual task questions in 11 subcategories (general and visual health, distance and near vision, colour and peripheral vision, ocular pain, driving, and vision-specific functioning and wellbeing), and is particularly sensitive to the influence of low vision from any cause. These activities are relatable to radiography clinical placement tasks of moving imaging equipment such as overhead x-ray tubes, patient trolleys, wheelchairs, mobile x-ray machines, and hoists that require spatial awareness (associated with near, distance, colour, and peripheral vision, driving, and vision-specific functioning tasks) within low light x-ray rooms and wards to acquire imaging. In addition to the associated tasks of image processing, reviewing, transmitting, storing, display of images and related computer-based examination confirmation tasks (near and colour vision), factoring in any accompanying impact of impaired general health, ocular pain, and wellbeing on these activities.

The VFQ-25 is the basis for the similar World Health Organisation (WHO) 20-item visual functioning questionnaire (VFQ-20)[34] for the study of visual impairment, and the socio-economic ADL.[30,31] Previous studies[35] have advised that in using participant-reported vision specific health status to estimate outcome measures, the VFQ-25 is an appropriate modelling method over other validated tools such as the EuroQol five dimensions (EQ-5D) questionnaire.[36]

The VFQ-25 psychometric data analysis utilises a two-step method,[32,33] firstly the participant values (1-5 Likert format scoring) are coded to 0-100% (highest possible score of 100% equals the best possible functioning). The second step involves averaging the subcategory scores to calculate final values, with an overall composite score created by averaging the subcategory (equal weighting) totals (but omitting the general health value) to gain an overall appraisal of the visual HRQOL of the participants, with results displayed in mean and standard deviation (SD) to quantify the variables. Cronbach's alpha coefficient was applied for internal consistency of the scale and Interclass Correlation Coefficient (ICC) for both intra-rater and inter-rater reliability was analysed using SPSS software (IBM Corp. Released 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp). Participants recorded demographics including age (VA deterioration is an age-related subtle change[7-10]), gender (previous studies have shown a predisposition to females[10]), and postcodes of home addresses for analysis of existing socioeconomic status, applying the English Indices of Deprivation 2015[37] (studies have shown a correlation of lower socioeconomic status to higher levels of visual impairment[11]).

The second stage applied a repeated measures of assessment design using computer based[38] monocular (OD = right eye, OS = left eye) and binocular (OU = both eyes) testing. Monocular testing applies a strong indication of any underlying visual defects but does not give a true reflection of how the study sample maintain daily VA activities as they do not walk around using vision from only one eye to attempt daily tasks. Normal VA is enhanced by binocular vision (both eyes together), if only binocular VA testing were applied the study would risk giving a misleading indicator as to the impact upon daily visual tasks from a defect in one eye. The better seeing (more functional) eye may provide some compensation for normal or acceptable VA when binocular vision is applied. Thus, testing of only binocular vision may provide an adequate level of VA, and an assumption of normal daily activities, but may not report the real impact of impaired VA of the study participants, potentially providing incorrect results as the compensation of using both eyes may mask underlying issues.

Monocular VA testing applied the Logarithm of the Minimum Angle of Resolution (LogMAR) VA charts (Figure 1A).[39-40] The LogMAR VA test is recommended for use by the RCOphth,[39] the National Vision Research Institute of Australia[40] and the WHO Standards for Characterization of Vision Loss and Visual Functioning.[41] Participant's monocular VA ability required the participants to cover the opposite eye (from the side being tested) with a blank card to block the vision (without applying pressure that would affect the eye performance in future tests). The LogMAR VA test used black Sloan font (Optotypes[31]) letters on a white background (contrast ratio 98%[34]) to check normal or corrected-to-normal VA.[31] The validity in utilising letters provides objective scoring of the answer. Each chart contained five letters per line, with 14 rows of letters (D E F H N P R U V Z) each row decreased in font height (as proposed by Bailey and Lovie[39]). Verbal instructions were given to read the letters from the top down (left to right across each line). Once a line has been started, it is required to be completed if at least three out of five letters were missed, then the test was complete.[42] Each letter equated to a score of 0.02 log units, representing a total line score of 0.1 log units (logarithmic progression), displayed in the formula[42]:

```
LogMAR VA = LogMAR value of best line read + 0.02 x (number of letters missed)
```

These results are further checked for consistency with a repeated measure testing of binocular (OU) screening used computer-based VA testing applying a Snellen chart[39,43] (Figure 1B). The Snellen chart is recommended by the National Institute for Health and Care Excellence (NICE),[44] the RCOphth[39] and British Standards Institution (BS4274-1:2003).[45] The chart consists of ten letters (C D H K N O R S V Z). Approaches to reduce the risk of bias in answers from memorisation of VA chart order of letters, applied two VA charts, one for binocular (Snellen) and one for monocular (LogMAR) that present the letters but in a different random sequence to reduce recall memorisation and allow an accurate recording of the participants reading of the chart.

The LogMAR measurement records the participants observed detail down to 1 minute of visual angle, displayed as LogMAR 0.0 which correlates to the Snellen VA score of 20/20.[39,42,43] Monocular and binocular VA results were graded using the Visual Acuity Scale (VAS)[31] to standardise scores across the test. Each line was worth 5 VAS points, and each letter read was 1 VAS point (Table 1); thus a 20/20 score equated to a score of 100 VAS (50 VAS is 20/200 = loss of 50% vision).

Investigations have shown no significant difference in testing observers' performance in VA tests between wall mounted vision charts and electronic testing.[46,47] Studies by Peli and Bex[48] advise computer testing is more efficient as it offers adaptive measurement of thresholds using a wide range of VA charts. By applying computer testing it creates the same viewing environment as in the radiography field. The American College of Radiology[49] recommends a viewing distance of modern desktop workstations of 102cm or more for reviewing images. Each VA chart was displayed at a 1-metre viewing distance on a 22inch monitor (Ilyama Prolite B2283HS, 2.1-megapixel format, flicker-free 1920x1080 resolution, 12,000,000:1 contrast ratio, 250 cd/m^2 luminance, with an anti-reflective protective glass coating, and a pixel pitch of 0.248 x 476.6mm), which complies with the Royal College of Radiologists (RCR) recommended psychophysical performance of the human eye.[50] The screen size and spatial resolution matched the matrix of the image displayed (reducing interpolation artefacts such as aliasing, blur, and edge halo effects). The VA charts filled the whole display screen to reduce the interference of outside objects, such as menu bars and tools.

Human perceptual ability utilises the scotopic (rods)[51] which see in black and white (both the LogMAR and Snellen charts are black Optotypes on white background), and are more sensitive in low light levels. The fovea centralis in the cones of the eye are incredibly sensitive to bright light, which when overstimulated, decreasing resolve. The ambient luminance in the assessment room was measured at 500 Lux with LED lights, to reduce any influence of light from the study environment contributing to the display system luminance,[52] fluorescent strip lighting was not used as this tends to flicker and may interrupt the participants concentration. There are no recommended guidelines in the UK for lighting in radiology departments. The Chartered Institution of Building Service Engineers guidance through the Society of Light and Lighting has been written for offices with visual display units.[53] Radiology environments generally apply ambient lighting levels for image viewing although the RCR[53] do specify a Lux level as monitor luminance levels are dependent on monitor manufacturer. For VA testing Tidbury et al.[54] recommend an optimum room luminance at 500Lux, which is aligned to the recommended lighting level for vision testing rooms by the British Standards.[55] After testing the students OD and OS VA data was analysed against the LogMAR value of best line read + 0.02 x (number of letters missed), and the OU VA test data was assessed against the smallest Snellen row that was accurately recorded. Both the LogMAR (OD, OS) and Snellen (OU) results were matched to the relevant VAS (Table 1) and subcategorised against age, gender and vision correction, with comparison of gender subgroups (OS,OD, OU) with two tailed t-test p values.

Results

The cohort of 80 students were invited to participate, 10 students did not attend on the day of the study. The sample demographics (*n*=70, Table 2), contained a mean age of 26.4 years (9.19 SD). A minority of participants required aids to correct vision (*n*=9; 12.8%). The monocular vision results demonstrated 74% of participants (*n*=52/70) scored 100 VAS for OD (right eye), and 80% of participants (*n*=56/70) scored 100 VAS for OS (left eye), the results did not differ significantly between each eye (*p*=0.21) or a dominant eye input (Table 3, Figures 2A, B). Additionally, this confirmed that no anisometropia (the difference in vision between both eyes which can interfere with normal binocular vision) was present in the sample. Comparison by gender showed monocular OD (right eye) females (78.5% scored 100 VAS; *n*=44/56) to males (57.1% scored 100 VAS; *n*=8/14) OD scores were not significant in differences (*p*=0.10), although there was a gender distribution of 80% females in the sample which may explain the result. Monocular OS (left eye) female scores (82.1% scored 100 VAS; *n*=46/56) compared to males (71.4% scored 100 VAS; *n*=10/14) OS scores were not significant in differences (*p*=0.27).

The mean monocular (OS and OD) VAS scores (Table 3, Figures 2A, 2B) displayed no apparent correlation to the mean binocular (OU) VAS scores by age and VAS outcomes (Table 3, Figure 2C). The participant's binocular (OU) vision all scored at or above the VAS normal vision level and were considerably better than the monocular (OS and OD) testing (Table 3). The student that met the normal OU 100 VAS score wore corrected visual aids. No students were rated at a VAS level of visual impairment (Table 1 compared to Table 3 results).

The results of the VFQ-25 (Table 4) reflected a high overall HRQOL mean score of 96.9 (3.9 SD), and the scores showed no concerns displayed by the participants that may impact their ADL (Table 4). Males (20-29 years) scored the highest for general health, with general vision showing a consistent response across all participant categories (Table 5). Although, the mean driving related score (75%) was assessed as showing a little difficulty by the participants. The SD scores demonstrate the dispersion of the dataset from the mean displaying a significant variance in responses relating to issues with driving-related spatial awareness and low light level driving, predominately in the <30 year age subcategory. The VFQ-25 Cronbach's alpha coefficient was 0.85 for the whole sample subscales items totalled (Table 5) showing an acceptable measure of internal consistency reliability[56] (scoring analysis showed the VFQ-25 driving subscale had the highest individual Cronbach alpha score, followed by ocular pain, vision-specific dependency and distance activities. The lowest VFQ-25 concordance score was the vision specific role dependency answers which was related to the low number of questions and poor inter-relatedness between the items. The VFQ-25 Cronbach alpha and ICC scores suffered from low to little variance in answers between-subject and within-subject (irrelevant of their socioeconomic backgrounds and ages) in the different vision specific questions of social function, mental health, role difficulties and dependency.

The socioeconomic status as the Index of Multiple Deprivation Rank[37] ranged from 32,567 to 423, and when grouped into categories of 1 (most deprived areas) to 10 (least deprived areas[37]), based on the seven domains of income, employment, education, health, crime, barriers to housing, and living environment (displayed in Table 6, Figure 3A) showed minor variation of mean scores per age group by a step of two indices. The data highlighted that female student's backgrounds contained no significant difference in mean values to males (as shown in box plot display of variation of upper and lower quartiles and spread of background scores, Table 6, Figure 3B). Comparison of socioeconomic by age status (Figure 3A) to monocular (Figure 2A OD, 2B OS) and binocular (Figure 2C OU) and VFQ-25 results (Table 4) demonstrate no trend lines linked to low VAS or HRQOL overall composite score. Likewise, socioeconomic status by gender category (Figure 3B) to VFQ-25 results (Table 4) has no statistical correlations of low HRQOL overall composite score.

Discussion

The VFQ-25 HRQOL provided a useful instrument to measure the self-reported scores associated with being able to complete visual functionating tasks related to ADL independently. Within this sample of student radiographers related to everyday clinical placement activities of spatial awareness in moving equipment, performing examinations and completing computer image processing and health records completion. The levels of responses in the VFQ-25 sub-scales mean scores reported within the age, gender and aided vision subcategories concluded the quality of their general visual functioning, social functioning and visual dependency, confirmed with the HRQOL overall composite score strongly indicated no associated risks to completing clinical placement tasks.

The VFQ-25 results compared against the index of multiple deprivation decile showed no direct socioeconomic impact of backgrounds to ADL or VA, and this was consistent against subcategories of age and gender. The Cronbach's alpha coefficient of the total subscales concluded internal consistency was efficient with a moderate degree of internal consistency and reliability over the subscales. These results were similar to Sivaprasad et al[57] study of applying the VFQ-25 on a sample of 100 participants for minor age-related macular degeneration, and Kovac et al.[58] on a sample of 105 participants with minor visual impairment which correlated a good to excellent score for test-retest reliability applying the VFQ-25 HRQOL as a methodological rigour.

Donders and Moore[59] in their creation of VA charts and threshold levels to assess visual function acknowledged that their standard (20/20) represented less than perfect vision, and the majority of participants tested achieved higher levels. Conceding this, we should possibly not refer to 100 VAS (and the LogMar/Snellen equivalent score) as the "normal" standard, but potentially as a "lower limit of normal" or a level of acceptance screening with no need for further investigation required. Studies[31,7-8] have indicated that the average adult VA is significantly better and does not drop to 100 VAS until after the age of 60. The participants (18-52 years) functional VA level all scored 100 VAS or better without evidence of significant impairment, although it was highlighted that binocular VA scored better than monocular VA in 22% of subjects. The results of the HRQOL in combination with the VAS (OU, OS, OD tests) did not identify through health evaluation and subgroup comparison (Tables 4 and 5), trend monitoring (Figure 2A-C and 3A and 3B), and risk factor identification (Tables 2 and 7) any potential within this sample group that their VA and visual functioning would impact upon any radiography clinical placement tasks and activities of moving imaging equipment (x-ray tubes, patient trolleys, wheelchairs, mobile x-ray machines, hoists) or associated reading tasks of image processing, reviewing, transmitting, storing, display of images.

A study by Lanca et al[60] which included reported mean participant OU LogMAR results of 20/14 were equivalent to our mean OU result of 107 VAS (20/14). Although it is recognised that variances in the method applied in the Lanca et al[60] study make comparison of results limited (smaller sample size, participant demographics included qualified radiographers and medical physicists, distance VA testing used wall charts in low light, and near VA testing in well-lit environments, with only LogMAR testing[60]). Comparison can also be to the Safdar et al.[61] study of the VA of consultant radiologists that reported a mean OU VA of 20/15 using a health screening questionnaire and a modified LogMAR chart throughout the day of radiology tasks, which likewise found no disconcerting findings in their VA.

This study considered prior to data collection whether there is a necessity for occupational VA testing in student radiographer recruitment. Principally to introduce such a requirement conflicts with the Equality Act 2010,[62] which prohibits by law discrimination based on physical disability without appropriate evidence, although the opposing argument may cite public safety and reduction of risk such as the UK driving license requirements.[63]

There is little published empirical evidence to exclude applicants for training with low VA or weak stereopsis (binocular vision).[63-64] This is understandable as ethically setting up a clinical environment randomised control trial to estimate actual occupational error rates from defective VA could incur public harm. The use of virtual reality (VR) simulation of occupations (such as radiography VR training software) to test the influence of low VA in vision-related tasks and skills, may resolve to some extent these barriers to research and create a comparable experience of the effects of visual problems when undertaking VR clinical radiography placement tasks in an ethically safe virtual environment. However, the software may not be created to specifically totally recreate all real-world scenarios or patient risk (as designed for training to learn radiography examination tasks).

The accurate interpretation (reading task) of medical images is fundamental in radiography but relies on a host of factors. At a rudimentary level, there are two tasks, firstly the visual inspection of imaging (perceptual) followed by the accumulation of that data to surmise an opinion (cognition). Previous studies have attempted to reason how visual abilities are related to image interpretation errors, with evidence generated from the 1940's[65,66] to present day[67] in an attempt to single out specific reasons including VA. The range of research methods includes film reading tests[65,66] and eye-tracking studies,[68] to modern eye position recording techniques[69-72] and VA testing.[15,16,61,73,74] Present day research acknowledges human visual interpretation errors will occur, and many investigations now focus on digital assistance with Artificial Intelligence (AI) algorithms[75,76] and Computer Aided Detection (CAD)[77] tools. These aids however ultimately still rely on and do not replace human eye observations currently in UK clinical radiographic practice.

This is the first study at this time to apply both VA (OD, OS, OU) testing with an HRQOL evaluation to the demographic tested (student radiographers) which have a unique occupational reliance on visual ability. No evidence of a risk was present that would indicate within this sample that occupational VA testing in student radiographer recruitment should be considered. The results from this sample demonstrated no concerns of reduced VA that may impede completing radiography clinical placement activities relevant to low light x-ray rooms or ward environments to acquire imaging or moving imaging equipment (overhead x-ray tubes, patient trolleys, wheelchairs, mobile x-ray machines, and hoists) or computer image and text reading tasks. Current UK precautionary measures are in place post-qualification for radiographers relying on health and safety guidance and regular occupational health eye examinations set by the European Union (Directive 90/270/EEC),[78] and Health and Safety (Display Screen Equipment) Regulations 1992.[29]

Limitations

This study reviewed three of the four ICIDH[30] aspects of vision loss, covering the functional ability, generic skills and abilities of the individual and the socioeconomic backgrounds, but did not examine the anatomical structure of the participant's eyes. This would require physical examinations of each participants orbits with ophthalmoscopy and slitlamp biomicroscopy by experienced practitioners, although this provides relatively poor predictors to the severity of the participant's functional ability.[31]

The application of VA as a primary outcome measure due to its standardised format is a validated model.[39-45] It is of note that there has been reported criticism of the Snellen chart, as the letter elements used (Sloan optotypes) have varying accuracy dependent on the letter identified (C as an O shape, or vice versa) which may affect the threshold measurement.[79] Sloan optotypes were used in the LogMAR charts also, and are recommended by national and international guidance[39-45] for VA screening as the standard.

The results of this study were obtained under controlled environmental conditions, which only have implications for future VA testing utilising similar standards. Perception tasks completed under differing environments may produce potentially different results.

Conclusion

The study provided binocular and monocular data on visual function in a sample of student radiographers and indicated that their thresholds align to normal (or near-normal) VA standards. There was no found association between the participant's socioeconomic background, age, or gender that may influence VA ability reflected in the student reported HRQOL measures of visual function.

References

1. National Health Service. Colour vision deficiency (Colour blindness). Available at: https://www.nhs.uk/conditions/colour-vision-deficiency/(Accessed 17th Sept 2019).
2. National Institutes of Health and National Eye Institute. Eye Conditions and Diseases: Color Blindness. July 2019. Available at: https://nei.nih.gov/learn-about-eye-health/eye-conditions-and-diseases/color-blindness (Accessed 17th Sept 2019).
3. Spalding JA. Colour vision deficiency in the medical profession. Br J Gen Pract 1999; 1;49(443):469-75.
4. Hess RF, To L, Zhou J, Wang G, Cooperstock JR. Stereo vision: the haves and have-nots. i-Perception. 2015 Jul 30;6(3):2041669515593028. Available at: https://journals.sagepub.com/doi/full/10.1177/2041669515593028 (Accessed 17th Sept 2019).
5. Wajuihian SO, Hansraj R. Stereoacuity and refractive, accommodative and vergence anomalies of South African school children, aged 13–18 years. African Vision and Eye Health. 2018 Feb 26;77(1):1-8. Available at: https://avehjournal.org/index.php/aveh/article/view/400/782 (Accessed 17th Sept 2019).
6. Miller LJ, Mittenberg W, Carey VM, McMorrow MA, Kushner TE, Weinstein JM. Stereopsis caused by traumatic brain injury. Arch Clin Neuropsych 1999;1;14(6):537-43.
7. Elliott DB, Yang KC, Whitaker D. Visual acuity changes throughout adulthood in normal, healthy eyes: seeing beyond 6/6. Optometry and vision science: official publication of the American Academy of Optometry 1995;72(3):186-91.
8. Haegerstrom-Portnoy G, Schneck ME, Brabyn JA. Seeing into old age: vision function beyond acuity. Optometry Vision Sci 1999;1;76(3):141-58.
9. The Society and College of Radiographers. Work related musculo-skeletal disorders. The Society and College of Radiographers London 2014. Available at: https://www.sor.org/learning/document-library/work-related-musculo-skeletal-disorders-sonographers (Accessed 24th June 2019).
10. Taylor HR, Livingston PM, Stanislavsky YL, McCarty CA. Visual impairment in Australia: distance visual acuity, near vision, and visual field findings of the Melbourne Visual Impairment Project. Am J Ophthalmol 1997;1;123(3):328-37.
11. Yip JL, Luben R, Hayat S, Khawaja AP, Broadway DC, Wareham N, Khaw KT, Foster PJ. Area deprivation, individual socioeconomic status and low vision in the EPIC-Norfolk Eye Study. J Epidemiol Community Health 2014;1;68(3):204-10.
12. Manning D, Barker-Mill SC, Donovan T, Crawford T. Time-dependent observer errors in pulmonary nodule detection. Br J Radiol 2006;79(940):342-346.
13. Christensen EE, Dietz GW, Murry RC, Moore JG. The effect of fatigue on resident performance. Radiology 1977;125(1):103-105.
14. Vertinsky T, Forster B. Prevalence of eye strain among radiologists: influence of viewing variables on symptoms. Am J Roentgenol 2005;184:681–6.
15. Halpenny D, O'Driscoll D, Torreggiani WC. Ocular health among radiologists in the age of PACS: is it time for our profession to open its eyes to this issue in light of existing European legislation?. Br J Radiol 2012;85(1020):e1309-11.
16. Krupinski EA. The role of perception in imaging: past and future. InSeminars in nucl med 2011;1 (41; 6)392-400.
17. Universities and Colleges Admissions Service 2017. Search for courses website. Available at: http://search.ucas.com/search/providers?Vac=1&AvailableIn=2017&Query=radiography&IsFeatherProcessed=True&MaxResults=1000&page=2 (Accessed 6th June 2017).
18. NHS Employers. Criminal Record Checks Standard. NHS Employers 2019. Available at: https://www.nhsemployers.org/-/media/Employers/Publications/employment-check-standards/Criminal-record-checks.pdf?la=en&hash=01BC67B53C2BD0175B40704E91CF2FAB0F15C021 (Accessed 24th June 2019).

19. Police Act 1997 (Criminal Records) (Amendment) Regulations 2013. Available at: http://www.legislation.gov.uk/uksi/2013/1194/pdfs/uksi_20131194_en.pdf (Accessed 24th June 2019).
20. NHS Employers. Values based recruitment. NHS Employers 2019. Available at: https://www.nhsemployers.org/your-workforce/recruit/employer-led-recruitment/values-based-recruitment (Accessed 24th June 2019)
21. Health Education England. Values based recruitment 2017. Available at: https://www.hee.nhs.uk/printpdf/our-work/attracting-recruiting/values-based-recruitment (Accessed 6th June 2017).
22. The Scottish Government. Everyone Matters: 2020 Workforce Vision implementation Plan 2016-17. Available at: http://www.gov.scot/Resource/0049/00490303.pdf (Accessed 6th June 2017).
23. NHS Wales. Values Based Recruitment – A Framework for Higher Education Institutions (HEI) 2017. Available at: http://www.weds.wales.nhs.uk/sitesplus/documents/1076/vbr%20framework%20wales%20final.pdf (Accessed 6th June 2017).
24. The Mid Staffordshire NHS Foundation Trust Public inquiry: Final report 2015. Available at: http://webarchive.nationalarchives.gov.uk/20150407084003/http://www.midstaffspublicinquiry.com/report (Accessed 24th June 2019).
25. NHS England. Keogh, B: Review into the quality of care and treatment provided by 14 hospital trusts in England: overview report 2013. Available at: https://www.nhs.uk/NHSEngland/bruce-keogh-review/Documents/outcomes/keogh-review-final-report.pdf (Accessed 24th June 2019).
26. Health Professions Admission Test- Ulster. Available at: https://hpat-ulster.acer.org/about-hpat-ulster (Accessed 24th June 2019).
27. Teesside University, Diagnostic Radiography Admissions Test. Available at: http://www.tees.ac.uk/docs/DocRepo/Courses/Radiography_sample.pdf (Accessed 24th June 2019).
28. The Royal College of Ophthalmologists. Ophthalmic services guidance: occupational visual standards. 2013. Available at: http://bmec.swbh.nhs.uk/wp-content/uploads/2013/03/OCCUPATIONAL-VISUAL-STANDARDS.pdf (Accessed 24th June 2019).
29. Health and Safety (Working with Display Screen Equipment) Regulations 1992 INDG36(rev4), HMSO, London 2013. Available at: http://www.hse.gov.uk/pubns/indg36.pdf (Accessed 24th June 2019).
30. World Health Organisation. International Classification of Functioning, Disability and Health (ICF).Geneva: WHO 2013. Available at: https://www.who.int/classifications/icf/en/ (Accessed 24th June 2019).
31. Colenbrander A. Measuring vision and vision loss. Chapter 51, volume 5. In: Duane TD, Tasman W, Jaeger EA. Duane's clinical ophthalmology, Philadelphia: Lippincott Williams & Wilkins, 2001, p.1-39.
32. National Eye Institute. Visual Functioning Questionnaire- 25 (VFQ-25) Version 2000. Available at: https://nei.nih.gov/sites/default/files/nei-pdfs/vfq_sa.pdf (Accessed 24th June 2019).
33. Mangione CM, Lee PP, Gutierrez PR, Spritzer K, Berry S, Hays RD. Development of the 25-item National Eye Institute Visual Function Questionnaire. Arch Ophthalmol 2001; 119:1050-1058.
34. World Health Organisation. Prevention of Blindness and Deafness: Consultation on development of standards for characterization of vision loss and visual functioning. WHO/PBL/03.91. 2003. Available at: http://apps.who.int/iris/bitstream/10665/68601/1/WHO_PBL_03.91.pdf (Accessed 24th June 2019).
35. Kay S, Ferreira A. Mapping the 25-item National Eye Institute visual functioning questionnaire (NEI VFQ-25) to EQ-5D utility scores. Ophthalmic Epidemiol 2014; 1;21(2):66-78.
36. Kind P, Dolan P, Gudex C, Williams A. Variations in population health status: results from a United Kingdom national questionnaire survey. BMJ 1998;316(7133):736-41.

37. Ministry of Housing, Communities and Local Government. English Indices of Deprivation 2015 (LSOA). Available at: http://imd-by-postcode.opendatacommunities.org/ (Accessed 24th June 2019).
38. Ehrmann K, Fedtke C, Radić A. Assessment of computer generated vision charts. Contact Lens and Anterio 2009;1;32(3):133-40.
39. The Royal College of Ophthalmologists. Snellen and LogMAR acuity testing. 2015. Available at: https://www.rcophth.ac.uk/wp-content/uploads/2015/11/LogMAR-vs-Snellen.pdf (Accessed 24th June 2019).
40. Bailey IL, Lovie JE. New design principles for visual acuity letter charts. Am J Optom Phys Opt 1976;53(11):740-5.
41. World Health Organisation. Standards for Characterization of Vision Loss and Visual Functioning, WHO/PBL/03.91 2003. Available at: https://apps.who.int/iris/bitstream/handle/10665/68601/WHO_PBL_03.91.pdf?sequence=1&isAllowed=y (Accessed 24th June 2019).
42. Holladay JT. Proper method for calculating average visual acuity. J Refract Surg 1997;1;13(4):388-91.
43. International Council of Ophthalmology. Visual Acuity Measurement Standard 1988. Available at: http://www.icoph.org/dynamic/attachments/resources/icovisualacuity1984.pdf (Accessed 24th June 2019).
44. National Institute for Health and Care Excellence. Health and social care directorate, Quality standards and indicators, Briefing paper: Serious Eye Disorders 2018. Available at: https://www.nice.org.uk/guidance/qs180/documents/briefing-paper (Accessed 24th June 2019).
45. British Standards Institution. Visual acuity test types. Test charts for clinical determination of distance visual acuity. Specification 4274-1:2003. Available at: https://shop.bsigroup.com/ProductDetail/?pid=000000000030021439&_ga=2.63268079.198447227.1561380921-1390851084.1561380921 (Accessed 24th June 2019).
46. Whatham AR, Mermoud C, Deruaz A, Goldschmidt M, Zesiger P, Safran AB. Computer-based measurement of letter and word acuity. Ophthalmic Physiol Opt 2006; 26(2):156–168.
47. Rosser DA, Murdoch IE, Fitzke FW, Laidlaw DA. Improving on ETDRS acuities: design and results for a computerised thresholding device. Eye 2003:17(6):701–706.
48. Pelli DG, Bex P. Measuring Contrast Sensitivity. Vision Res 2013;90:10–14.
49. Hirschorn, D S. Krupinski, EA. Flynn, MJ. IT reference guide for the practicing radiologist. The American College of Radiology. 2013. Available at: https://www.acr.org/~/media/ACR/Documents/PDF/Advocacy/IT%20Reference%20Guide/IT%20Ref%20Guide%20Displays.pdf (Accessed 6th June 2017).
50. The Royal College of Radiologists, IT clinical documents: Picture archiving and communications systems (PACS) and guidelines on diagnostic devices. Second edition 2012. Available at: https://www.rcr.ac.uk/sites/default/files/docs/radiology/pdf/BFCR%2812%2916_PACS_DDD.pdf (Accessed 24th June 2019).
51. Hood DC, Finkelstein MA. Sensitivity to light. In: Boff K, Kaufman L, Thomas J, editors. Handbook of Perception and Human Performance: Vol 1. Sensory Processes and Perception, New York: Wiley, 1986.
52. Brennan PC, McEntee M, Evanoff M, Phillips P, O'Connor WT, Manning DJ. Ambient lighting: effect of illumination on soft-copy viewing of radiographs of the wrist. Am J Roentgenol 2007;188(2):177-80.
53. Royal College of Radiologists. Picture archiving and communication systems (PACS) and guidelines on diagnostic display devices. 2012. London, UK.
54. Tidbury LP, Czanner G, Newsham D. Fiat Lux: the effect of illuminance on acuity testing. Graefe's Archive for Clinical and Experimental Ophthalmology. 2016 Jun 1;254(6):1091-7. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4884565/

55. British Standards Institute (2011) BS EN 12464–1:2011 < br />Light and Lighting—lighting of work places < br />Part 1: indoor work places. BS EN 12464–1:2011
56. Hair JF, Black WC, Babin BJ, Anderson RE. Multivariate Data Analysis. 7th ed. Harlow: Pearson New International; 2009.
57. Sivaprasad S, Tschosik E, Kapre A, Varma R, Bressler NM, Kimel M, Dolan C, Silverman D. Reliability and Construct Validity of the NEI VFQ-25 in a Subset of Patients With Geographic Atrophy From the Phase 2 Mahalo Study. Am J Ophthalmol 2018:1;190:1-8.
58. Kovac B, Vukosavljevic M, Kovac JD, Resan M, Trajkovic G, Jankovic J, Smiljanic M, Grgurevic A. Validation and cross-cultural adaptation of the National Eye Institute Visual Function Questionnaire (NEI VFQ-25) in Serbian patients. Health Qual Life Out 2015;3(1):142.
59. Donders FC, Moore WD. On the anomalies of accommodation and refraction of the eye: With a preliminary essay on physiological dioptrics. New Sydenham Society 1864;22.
60. Lanca C, Lanca L, Thompson J, Hogg P. Visual function assessment in medical imaging research. Radiography. University of Salford 2014; Available at: http://usir.salford.ac.uk/id/eprint/36948/3/RADT_ND_VisualFunctionPR_ToAuthor-%20PH%20edit[1].pdf:public (Accessed 17th Sept 2019).
61. Safdar NM, Siddiqui KM, Qureshi F, Mirza MK, Knight N, Nagy P, Siegel E. Vision and quality in the digital imaging environment: how much does the visual acuity of radiologists vary at an intermediate distance? Am J Roentgenol 2009;192:335–40.
62. Equality Act 2010. Available at: http://www.legislation.gov.uk/ukpga/2010/15/contents (Accessed 24th June 2019).
63. Wong NW, Stokes J, Foss AJ, McGraw PV. Should there be a visual standard for ophthalmologists and other surgeons?. Postgrad Med J 2010;1;86(1016):354-8.
64. Elliot A. Is stereopsis essential to be a competent ophthalmic surgeon? Royal College of Ophthalmologists: London, 2008.
65. Birkelo CC, Chamberlain WE, Phelps PS. Tuberculosis case finding. A comparison of the effectiveness of various roentgenographic and photofluorographic methods. JAMA 1947;133:359-366.
66. Garland LH. On the scientific evaluation of diagnostic procedures. Radiology 1949;52:309-328.
67. Newell RR, Chamberlain WE, Rigler L: Descriptive classification of pulmonary shadows; a revelation of unreliability in the roentgenographic diagnosis of tuberculosis. Am Rev Tuberc 1954;69:566-584.
68. Tuddenham WJ, Calvert WP. Visual search patterns in roentgen diagnosis. Radiology 1961;76:255-256.
69. Kundel HL, Nodine CF, Carmody D. Visual scanning, pattern recognition and decision-making in pulmonary nodule detection. Invest Radiol 1978;13:175-181.
70. Nodine CF, Kundel HL. Using eye movements to study visual search and to improve tumor detection. Radiographics 1987;7:1241-1250.
71. Krupinski EA. The importance of perception research in medical imaging. Radiat Med 2000;18(6):329-34.
72. Nocum DJ, Brennan PC, Huang RT, Reed WM. The effect of abnormality-prevalence expectation on naïve observer performance and visual search. Radiography. 2013;19(3):196-9. Available at: https://www.sciencedirect.com/science/article/pii/S1078817413000448 (Accessed 17th Sept 2019).
73. Quaghebeur G, Bhattacharya JJ, Murfitt J. Radiologists and visual acuity. Eur Radiol 1997;7:41–3.
74. Thompson JD, Lança C, Lança L, Hogg P. A method to determine the impact of reduced visual function on nodule detection performance. Radiography. 2017 Feb 1;23(1):19-24. Available at: https://www.sciencedirect.com/science/article/pii/S1078817416300463 (Accessed 17th Sept 2019).

75. Thian YL, Li Y, Jagmohan P, Sia D, Chan VE, Tan RT. Convolutional Neural Networks for Automated Fracture Detection and Localization on Wrist Radiographs. Radiol: Artif Intell 2019;30;1(1):e180001.
76. Liu K, Li Q, Ma J, Zhou Z, Sun M, Deng Y, Tu W, Wang Y, Fan L, Xia C, Xiao Y. Evaluating a Fully Automated Pulmonary Nodule Detection Approach and Its Impact on Radiologist Performance. Radiol: Artif Intell 2019;1(3):e180084.
77. Taylor P, Given-Wilson RM. Evaluation of computer-aided detection (CAD) devices. Br J Radiol 2005;78(suppl_1):S26-30.
78. Council of the European Union (1990) Council Directive 90/270/EEC of 29 May 1990 on the minimum safety and health requirements for work with display screen equipment (fifth individual Directive within the meaning of Article 16 (1) of Directive 89/391/EEC). Luxembourg: Office for Official Publications of the European Communities. 1990 Available at: https://osha.europa.eu/en/legislation/directives/5 (Accessed 24th June 2019).
79. Mathew JA, Shah SA, Simon JW. Varying difficulty of Snellen letters and common errors in amblyopic and fellow eyes. Arch Ophthalmol 2011;129(2):184-7.

Figure 1A. Snellen VA Chart (example shown not to scale but for illustration purposes).

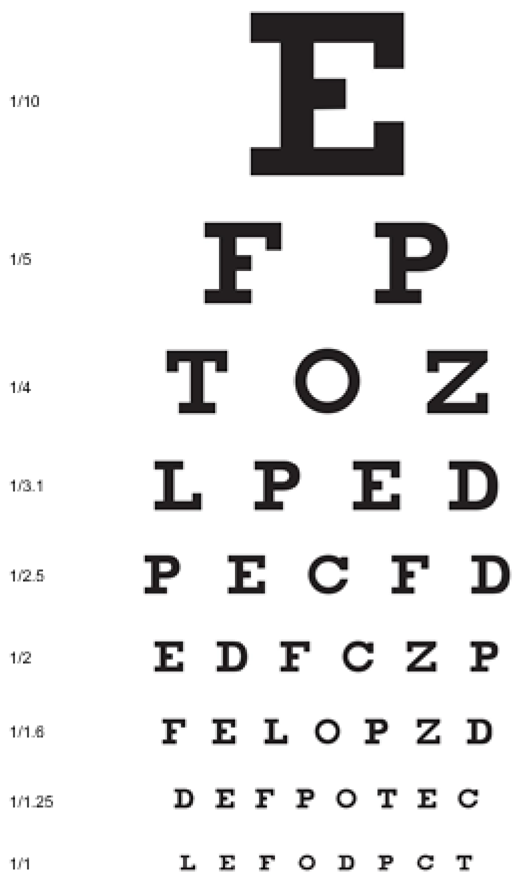

Figure 1B. Logarithm of the Minimum Angle of Resolution (LogMAR) AV chart (example shown not to scale but for illustration purposes).

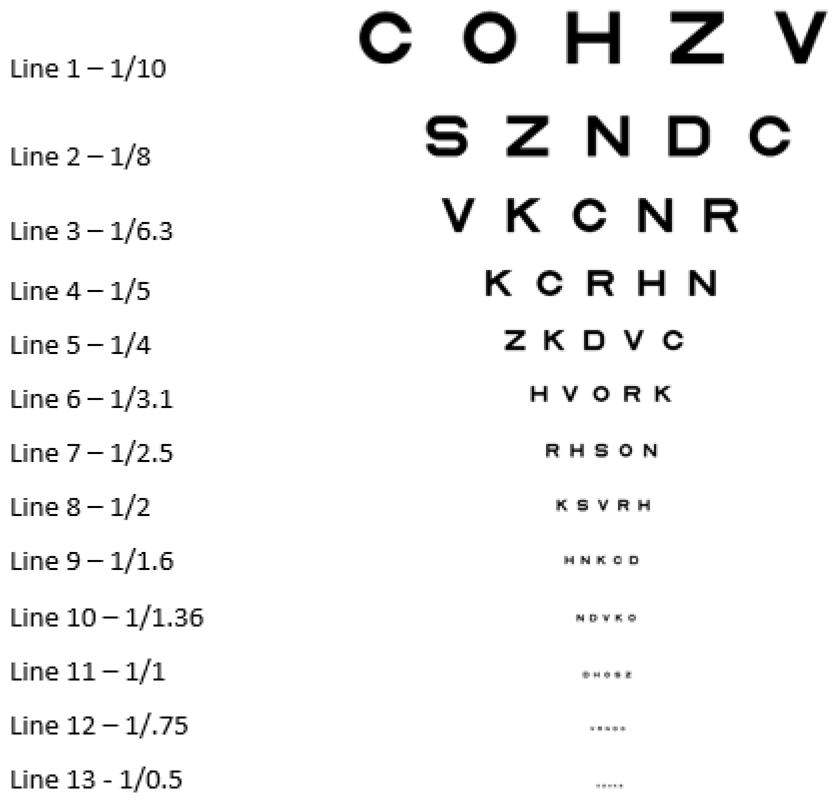

Table 1. Correlation of LogMAR, Snellen and VAS scores (normal range shaded).

WHO ICIDH Range		Snellen Scale	LogMAR Scale	Visual Acuity Score (VAS)
(Near-) Normal Vision	*Range of Normal Vision*	20/12.5	-0.2	110
		20/16	-0.1	105
		20/20	*0*	*100*
		20/25	+0.1	95
	Near-Normal Vision	20/32	0.2	90
		20/40	0.3	85
		20/50	0.4	80
		20/63	0.5	75
Low Vision	*Moderate Low Vision*	20/80	0.6	70
		20/100	0.7	65
		20/125	0.8	60
		20/160	0.9	55
	Severe Low Vision	20/200	+1.0	50
		20/250	1.1	45
		20/320	1.2	40
		20/400	1.3	35
	Profound Low Vision	20/500	1.4	30
		20/630	1.5	25
		20/800	1.6	20
		20/1000	1.7	15
(Near-) Blindness	*Near-Blindness*	20/1250	1.8	10
		20/1600	1.9	5
		20/2000	+2.0	0
	Blindness	No Light Perception		

Table 2. Sample group characteristics.

Characteristics	*n* (%)
Age	
18-19	20 (28.6%)
20-29	30 (42.9%)
30-39	12 (17.1%)
40-49	6 (8.6%)
50-60	2 (2.8%)
Gender	
Female	56 (80%)
Male	14 (20%)
Aided vision	
Glasses	9 (12.8%)
No Glasses	61 (87.2%)

Table 3. Monocular (OD, OS) and binocular (OU) eye results showing participant numbers per sample group (top x-axis) and VAS result category (side y-axis).

Monocular OD	Age					Gender		Aided Vision	
VAS	<19	20-29	30-39	40-49	>50	Female	Male	Yes	No
110									
105									
100	17	20	11	4		44	8	7	45
95	3	6	1	2	2	9	5	1	13
90		3				3			3
85		1					1	1	
Monocular OS	**Age**					**Gender**		**Aided Vision**	
VAS	<19	20-29	30-39	40-49	>50	Female	Male	Yes	No
110									
105									
100	17	26	9	4		46	10	8	48
95	3	3	3	1	2	9	3	1	11
90		1		1		1	1		2
85									
Binocular OU	**Age**					**Gender**		**Aided Vision**	
VAS	<19	20-29	30-39	40-49	>50	Female	Male	Yes	No
110	6	20	7	2		28	8	3	32
105	15	10	5	4		28	5	5	29
100					1		1	1	
95									
90									
85									

Table 4. VFQ-25 results displaying number of participants per subcategory, mean score of the sample of participants in each subcategory (top x-axis) against VFQ-25 question (side y-axis) and standard deviation (SD) of the result.

	Age										Gender				Aided Vision			
	<19		20-29		30-39		40-49		>50		Female		Male		Yes		No	
VFQ-25	*n*	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD
General health	20	74 ± 21	30	81 ± 16	12	75 ± 21	6	79 ± 25	2	75 ± 35	56	76 ± 19	14	82 ± 18	9	75 ± 13	61	78 ± 20
General vision	20	84 ± 10	30	88 ± 11	12	87 ± 10	6	87 ± 10	2	80 ± 0	56	86 ± 11	14	86 ± 9	9	84 ± 9	61	86 ± 11
Ocular pain	20	92 ± 15	30	91 ± 12	12	94 ± 13	6	88 ± 11	2	88 ± 0	56	91 ± 13	14	93 ± 11	9	82 ± 14	61	93 ± 12
Near activities	20	96 ± 5	30	97 ± 5	12	97 ± 7	6	90 ± 20	2	92 ± 0	56	96 ± 8	14	97 ± 4	9	94 ± 6	61	96 ± 8
Distance activities	20	95 ± 8	30	97 ± 6	12	100 ± 0	6	87 ± 27	2	92 ± 12	56	96 ± 11	14	96 ± 6	9	95 ± 6	61	96 ± 10
Vision-specific social function	20	99 ± 3	30	100 ± 0	12	100 ± 0	6	98 ± 5	2	100 ± 0	56	100 ± 2	14	100 ± 0	9	100 ± 0	61	100 ± 2
vision-specific mental health	20	94 ± 9	30	95 ± 7	12	96 ± 5	6	91 ± 7	2	94 ± 0	56	94 ± 8	14	96 ± 5	9	93 ± 6	61	95 ± 8
Vision-specific role difficulties	20	97 ± 9	30	97 ± 5	12	100 ± 0	6	90 ± 12	2	100 ± 0	56	97 ±7	14	97 ± 7	9	93 ± 9	61	97 ± 7
Vision-specific dependency	20	98 ± 6	30	99 ± 3	12	100 ± 0	6	100 ± 0	2	100 ± 0	56	99 ± 4	14	100 ± 0	9	100 ± 0	61	99 ± 4
Driving	20	70 ± 42	30	70 ± 43	12	91 ± 29	6	74 ± 38	2	100 ± 0	56	71 ± 42	14	90 ± 26	9	93 ± 7	61	72 ± 42
Colour Vision	20	100 ± 0	30	99 ± 5	12	100 ± 0	6	100 ± 0	2	100 ± 0	56	100 ± 0	14	98 ± 7	9	100 ± 0	61	100 ± 3
Peripheral Vision	20	99 ± 6	30	97 ± 9	12	100 ± 0	6	92 ± 20	2	100 ± 0	56	97 ± 9	14	98 ± 7	9	97 ± 8	61	98 ± 9
Overall Composite Score (HRQOL)	20	97 ± 5	30	97 ± 3	12	98 ± 2	6	94 ± 5	2	95 ± 1	56	97 ± 4	14	97 ± 3	9	96 ± 3	61	97 ± 4

Table 5. Overall HRQOL VFQ-25 results for the whole study sample, with Cronbach' Alpha measure of internal consistency, and Interclass Correlation Coefficient (top x-axis) against individual VFQ-25 question categories (side y-axis).

VFQ-25	Sample *n*	HRQOL Mean + SD	Cronbach's Alpha	Interclass Correlation Coefficient	95%CI
General health	70	78 + 19	*N/A*	*N/A*	*N/A*
General vision	70	86 + 11	*N/A*	*N/A*	*N/A*
Ocular pain	70	91 + 12	0.74	0.07	0.10-0.15
Near activities	70	96 + 8	0.57	0.56	0.35-0.71
Distance activities	70	96 + 10	0.71	0.69	0.55-0.80
Vision-specific social function	70	100 + 2	0.40	0.40	0.36-0.68
vision-specific mental health	70	94 + 7	0.36	0.22	0.30-0.55
Vision-specific role difficulties	70	97 + 7	0.35	0.35	0.21-0.35
Vision-specific dependency	70	99 + 4	0.72	0.71	0.53-0.82
Driving	70	75 + 40	0.89	0.63	0.42-0.69
Colour Vision	70	100 + 3	*N/A*	*N/A*	*N/A*
Peripheral Vision	70	98 + 9	*N/A*	*N/A*	*N/A*
Overall Composite Score (HRQOL)	70	97 + 4	0.85	0.54	0.36-0.68

Figure 2A. Monocular right (OD) eye results plotted to VA scores depicting the linear trend line relationship between the participant age sub categories (independent x- axis) and VAS scores (dependent y-axis) variables.

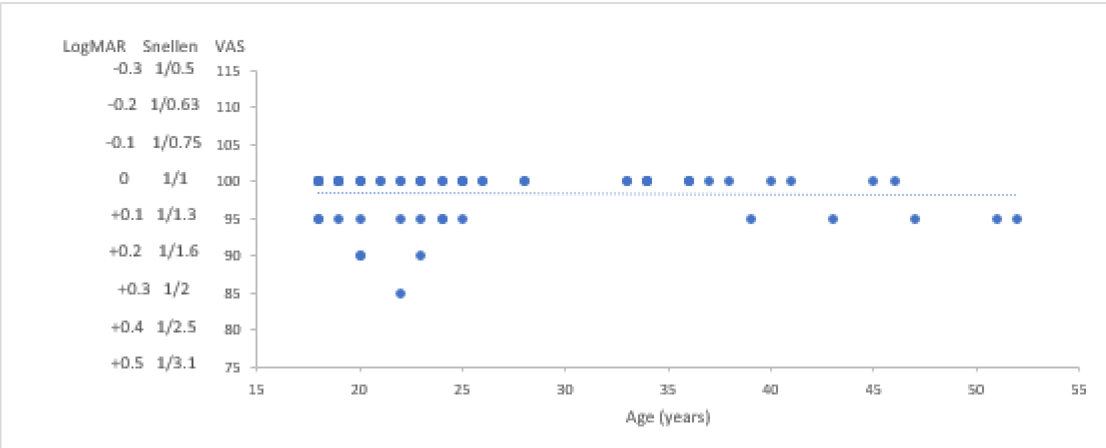

Figure 2B. Monocular left (OS) eye results plotted to VA scores depicting the linear trend line relationship between the participant age sub categories (independent x- axis) and VAS scores (dependent y-axis) variables.

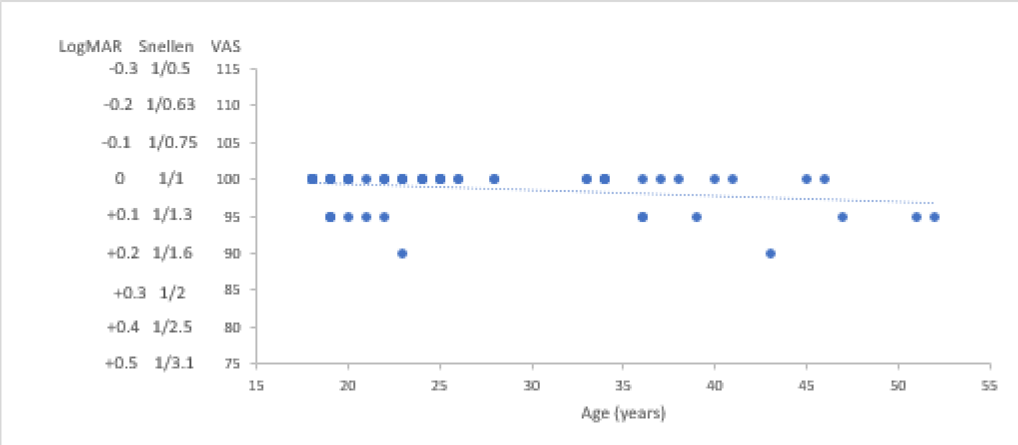

Figure 2C. Binocular (both, OU) eye results plotted to VA scores depicting the linear trend line relationship between the participant age sub categories (independent x- axis) and VAS scores (dependent y-axis) variables.

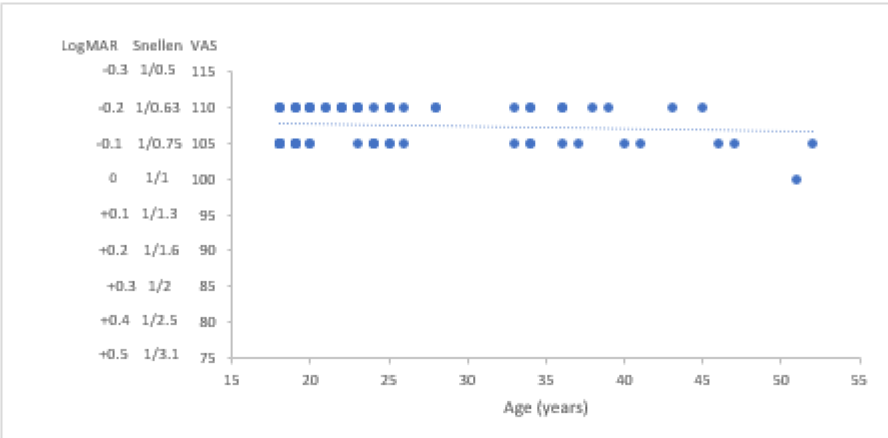

Figure 3A. Box plot display of variation of upper and lower quartiles and display of spread of Index of multiple deprivation decile scores plotted against participant age.

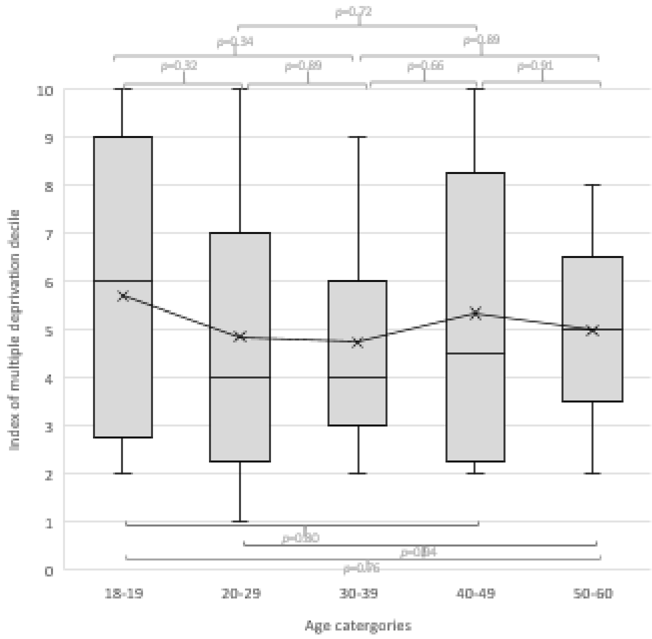

Figure 3B. Box plot display of variation of upper and lower quartiles and display of spread of Index of multiple deprivation decile scores plotted against gender.