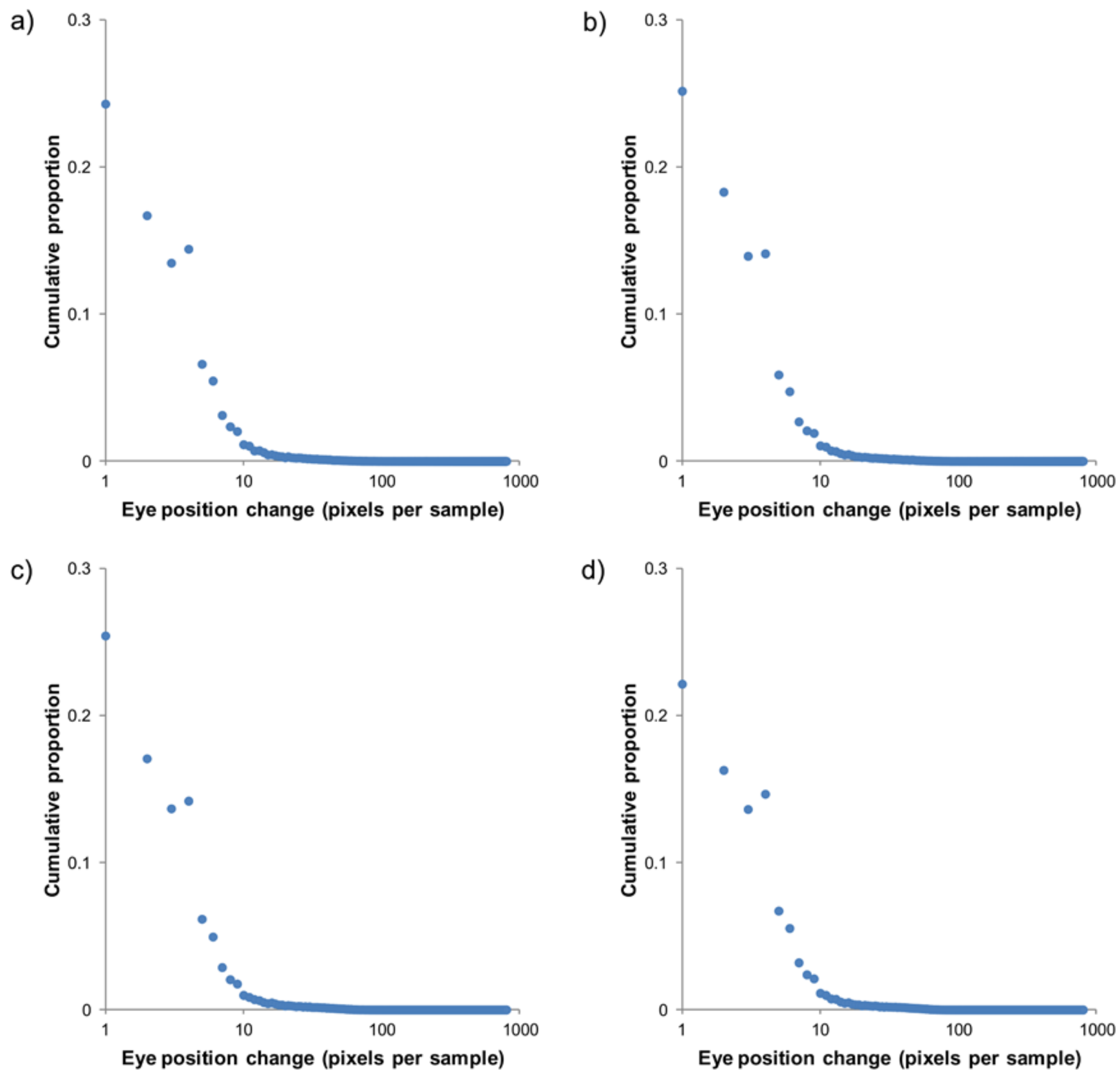
APPENDIX

The change in eye position between each 4 ms eye tracking sample was calculated as the absolute distance in gaze position between two adjacent samples. An example is shown in Figure A3. All data were converted from millimetres to pixels for further evaluation of the image structure at fixation locations. At our viewing distance of 57 cm, 1 mm corresponded to 3.2 pixels on the monitor display.

Eye movement data were then categorized into fixations or saccades. Figure A1 shows the distribution of eye position changes for all subjects for each artificial scotoma condition. Eye position data were collected at 250 Hz, so the data show the frequency of a change in eye position of a given size, in 1 pixel bins as shown on the log scaled x-axis, for each 4 ms interval. The distribution is unimodal, so there is no obvious division between saccades and fixations (note that this unimodality applies equally to velocity or acceleration, as both are simply displacement divided by functions of time). Any displacement, velocity or acceleration criterion used to separate fixations from saccades is therefore arbitrary

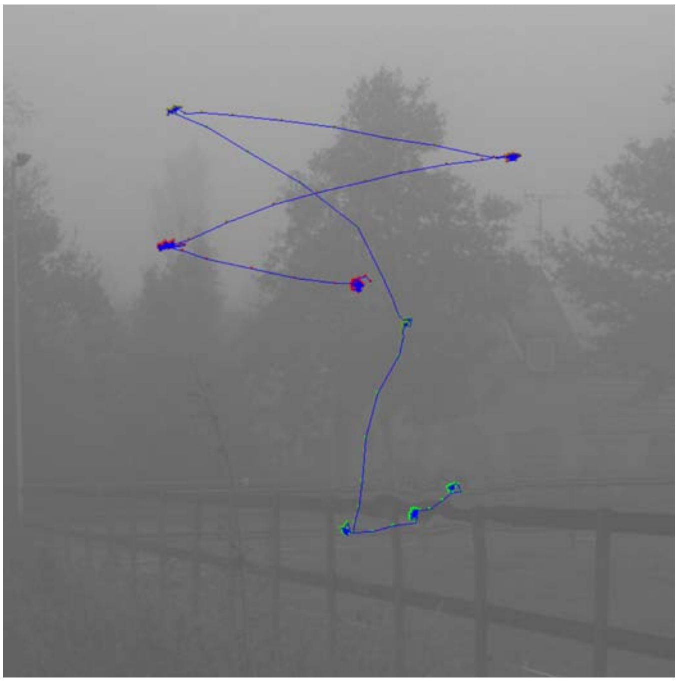


[Figure A1. Distribution of eye position changes obtained in each 4 ms sample for all observers for (a) control condition (for 166348 eye position changes), and for simulated central visual impairment conditions of (b) $\sigma_{x,y}$ = 1° (for 240595 eye position changes), (c) $\sigma_{x,y}$ = 2° (for 260635 eye position changes), (d) $\sigma_{x,y}$ = 4° (for 369715 eye position changes). Each distribution is unimodal, contrary to what a fixed criterion for saccade and fixation classifier would imply.]

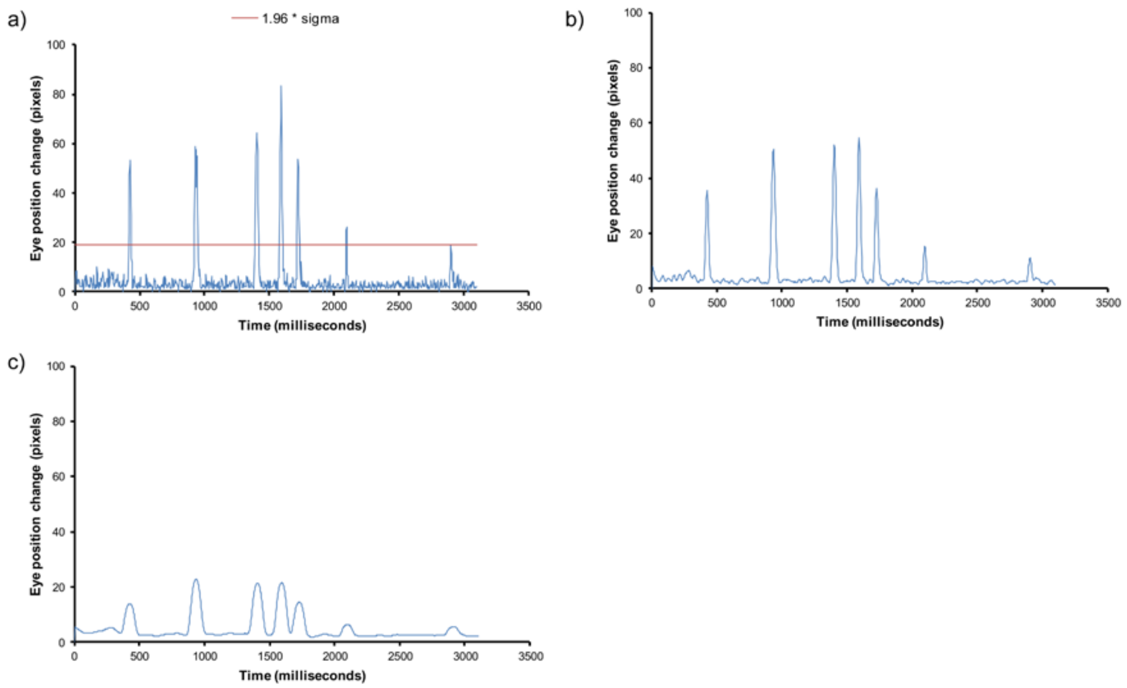
We considered two methods to classify fixation and saccades. Firstly, a single fixed criterion could be applied, so that all eye movements smaller than the criterion are classified as micro-saccades within a single fixation and eye movements greater than the criterion are classified as saccades between fixations. These criteria may consider the displacement, velocity or acceleration of tracked eye movements. Several studies analysing eye movements have incorporated a popular velocity criterion of 30° s^{-1}; [1-12].

Secondly, a statistical criterion could be applied. On each trial, eye movements were converted into z scores relative to the mean for each trial. A saccade can be defined statistically as any change in eye position greater than a criterion z score (i.e. multiples of σ) above the mean of all the changes in eye position made within a particular trial. This method was favoured over a fixed saccade criterion (e.g. displacement, velocity or acceleration) because it potentially allowed for variation in eye movement properties across experimental conditions. Such variation might be expected because central vision loss is known to increase fixation instability. Patients with central vision loss due to macular disease are less able to hold steady fixation than those with good foveal function [13-16]. The use of a fixed criterion cannot take into account any variation in eye movement behaviour between subjects and within subjects that might be caused by the artificial visual field loss in our experimental conditions. The criterion z score was selected at 1.96σ, which defines eye movements that are significantly greater than the average eye position change for the trial at a 95% confidence level. The classifications made with this criterion were then compared by eye with the gaze point traces (Figure A2) and eye position change data (Figure A3) for 100 images. We were satisfied that the classifications and the number of saccades and fixations identified with this method were in good agreement with our subjective evaluations of fixations and saccades. It can be seen from Figure A1 that the distributions did not vary greatly across the control and artificial scotoma conditions. With this method, the threshold for defining a saccade corresponded to a velocity of 172.36° s^{-1}, on average, across all subjects and conditions.

This criterion is significantly greater than the 30° s^{-1} fixed criterion commonly employed elsewhere, that would obviously have classified many more saccades than our method. Figure A2 and A3 show representative visual search data from our experiment. Our statistical method identified 8 fixations separated by 7 saccades for this search. The 30° s^{-1} fixed criterion identified 106 fixations separated by 105 saccades. Manual inspection of 20 randomly chosen visual search plots from each subject, 5 trials from each of the 4 conditions, similarly showed that a 30° s^{-1} fixed criteria classified the number of saccades to be far in excess of our own our introspective assessment of the search plot.



[Figure A2. An example of a typical visual search plot. The eye movement data have been superimposed on top of the experimental natural image. The number of saccades identified using our method and those with a fixed velocity criterion of ≥ 30° s^{-1} were 7 and 105 respectively.]



[Figure A3. (a) Eye position changes, in pixels, recorded as a function of time for Figure A2. Solid red line indicates 1.96σ above the mean of all eye position changes in this trial, corresponding to an amplitude of 18.93 pixels (0.59°). For figures (b) and (c), the 'lowess' function was accessed within MATLAB was used to smooth the data of the eye position data of figure (a) to reduce the level noise before a fixed criteria was applied. The 'lowess' function with (b) default weighting (saccade number = 41) and (c) weighting = 35 (saccade number = 8)]

We next examined if a fixed criterion could be applied if some of the micro-saccades and drifts that occur during fixations [17] were smoothed (note that low temporal frequency eye trackers effectively perform such smoothing). A 'lowess' locally weighted linear regression function was employed to smooth the eye position change data in an attempt reduce this noise. The output of this function is shown in figure A3 (b) and (c).

By manipulating the weighting function, the data can be smoothed to a point where the number of saccades classified fits the subjective impression, but with a reduction in the magnitude of the measured eye position change. Despite the merits of this procedure, it still requires the choice of an arbitrary weighting and that weighting might vary across subjects and conditions. In rehabilitation practice and research with patients with low vision the classification of saccade or fixation can be of utmost importance. If an inappropriate criterion were applied, one may end up with an unrepresentative depiction of a subject's fixational eye movements.

References

1. Crossland MD and Rubin GS. The use of an infrared eyetracker to measure fixation stability. Optom Vis Sci 2002;79:735-9.
2. Bellmann C et al. Fixation stability using central and pericentral fixation targets in patients with age-related macular degeneration. Ophthalmology 2004;111:2265-70.
3. Cornelissen FW, Bruin KJ, and Kooijman AC. The influence of artificial scotomas on eye movements during visual search. Optom Vis Sci 2005;82:27-35.
4. Crossland MD, Culham LE, and Rubin GS. Fixation stability and reading speed in patients with newly developed macular disease. Ophthalmic Physiol Opt 2004;24:327-33.
5. Crossland MD and Rubin GS. Eye movements and reading in macular disease: further support for the shrinking perceptual span hypothesis. Vision Res 2006;46:590-7.
6. Kabanarou SA et al. Gaze changes with binocular versus monocular viewing in age-related macular degeneration. Ophthalmology 2006;113:2251-8.
7. Macedo AF, Crossland MD, and Rubin GS. The effect of retinal image slip on peripheral visual acuity. J Vis 2008;8:16 1-11.
8. Bertera JH. The effect of simulated scotomas on visual search in normal subjects. Invest Ophthalmol Vis Sci 1988;29:470-5.
9. Henderson JM et al. Object identification without foveal vision: evidence from an artificial scotoma paradigm. Percept Psychophys 1997;59:323-46.
10. Coeckelbergh TR et al. The effect of visual field defects on driving performance: a driving simulator study. Arch Ophthalmol 2002;120:1509-16.
11. Coeckelbergh TR et al. The effect of visual field defects on eye movements and practical fitness to drive. Vision Res 2002;42:669-77.
12. Luo G and Peli E. Use of an augmented-vision device for visual search by patients with tunnel vision. Invest Ophthalmol Vis Sci 2006;47:4152-9.
13. Culham LE et al. Use of scrolled text in a scanning laser ophthalmoscope to assess reading performance at different retinal locations. Ophthalmic Physiol Opt 1992;12:281-6.
14. Steinman RM, Cushman WB, and Martins AJ. The precision of gaze. A review. Hum Neurobiol 1982;1:97-109.
15. White JM and Bedell HE. The oculomotor reference in humans with bilateral macular disease. Invest Ophthalmol Vis Sci 1990;31:1149-61.
16. Whittaker SG, Budd J, and Cummings RW. Eccentric fixation with macular scotoma. Invest Ophthalmol Vis Sci 1988;29:268-78.
17. Rucci M et al. Miniature eye movements enhance fine spatial detail. Nature 2007;447:851-4.