Reading impairment in the presence of simulated defocus, coma or secondary astigmatism

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Purpose

The human eye suffers from monochromatic aberrations, described by Zernike modes, that degrade the retinal image (see [1] for example). Clinically it is important to understand which types and amplitudes of aberration cause the greatest impact on visual performance. Using rendered aberrations it has been shown that the impairment of visual acuity varies between Zernike modes [2] such that those with low angular order affect acuity the most. The decline in visual acuity is reported to be proportional to the increase in rms wavefront error [3].

In this study we consider the effect of aberrations on a high-level task, such as reading, in which the processes of recognition are time-critical. Previous studies have shown a decline in reading performance for dioptric and diffuse blur. However, we know of no study investigating the effects of higher-order aberrations on reading performance. During reading the eyes make a series of movements, called saccades. Between these the eyes remain still, fixating for around 250 ms to obtain foveal and parafoveal visual information for word identification and for planning the next saccade. Optical aberrations cause phase and contrast changes that can affect the form and position of a letter, which in turn may disrupt word identification and saccade planning. Eye movement data in relation to a word's lexical frequency (its occurrence in language) provide insights into linguistic processing beyond the initial extraction of visual information (see [4] for example). We consider the influence of aberrations on these effects.

Methods

We selected three Zernike modes for investigation by considering their effects on letters. We considered the distinguishability of aberrated letters, by comparing them via a cross-correlation, and the position of an aberrated letter, by measuring its centre of gravity. Coma was the only mode to affect the centre of gravity significantly and we predicted secondary astigmatism would impact letter distinguishability the most. We also chose defocus as a low-order comparison.

Nineteen subjects participated in this study. Due to the large field of view required for reading and the necessity for eye movements we chose to study these aberrations in simulation rather than optically. Subjects read with natural pupil dilation and their ocular wavefronts were measured prior to testing to assess changes in the resulting retinal image. A set of 52 sentence frames were generated twice, with either a high or low lexical frequency target word of six letters embedded in the centre. Subjects were presented randomly with one version of the sentence and answered a comprehension question about each.

Results

Measures such as average fixation duration with respect to the control condition (no aberration) and lexical frequency dependent measures such as average gaze duration on the target word (all fixations before leaving the word) were calculated (see Figure 1).

When increasing the amplitude, secondary astigmatism had a greater effect on the average fixation duration than defocus. Coma had the smallest impact and the rate which impairment increased was lower. The lexical frequency effect was consistently large for defocus, indicating subjects struggled to identify low frequency words more. The lexical frequency effect was consistently low for coma, suggesting word identification was less impaired. Secondary astigmatism caused increasing cognitive impairment with increasing amplitude of aberration. Total reading times for the target word indicated secondary astigmatism impaired word identification the most overall.

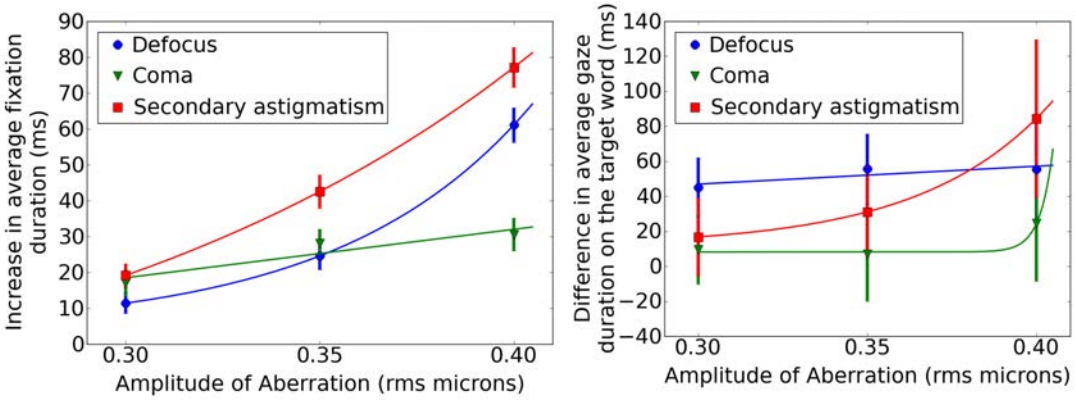

Fig. 1. The average fixation duration over a sentence (left) and the difference in average gaze duration between high and low frequency target words (right). The positive values on the right-hand graph indicate a lexical frequency effect was observed. The amplitude of aberration is that over a 3.5 mm pupil (the average pupil diameter during the experiment).

Conclusions

Secondary astigmatism impairs reading the most and coma impairs reading least. The magnitude of the lexical frequency effect was different across aberrations, suggesting the differences in image quality at the retina differentially impacted subsequent cognitive processes. These affects were largest for secondary astigmatism and we attribute this to the creation of inconsistent letter features due to phase changes in the image. These features lead to misidentification of orthographic information, and consequently, impaired word identification.

References

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