TITLE:

Binocular Temporal Visual Processing in Myopia

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Supplementary Appendix S1: **Monocular Contrast Sensitivity**

Sensitivity to temporal visual information can be characterized by measuring the temporal contrast sensitivity function (tCSF; De Lange, 1958a, 1958b). Similar to the spatial CSF, there is a gradual decrease at low temporal frequencies and a steep fall off at higher temporal frequencies, that both depend on the spatial frequency (SF) of the stimulus. The adult human tCSF is a band-pass function (Kelly, 1971) with peak sensitivity at approximately 8 Hz (Kelly, 1971) and a high frequency cut-off at approximately 60 Hz, known as the critical flicker frequency (CFF; Ong & Wong, 1971)

**Procedures:**

Temporal CSFs were measured while the display described in the methods section was viewed monocularly (without shutter glasses), and the untested eye occluded with an eye patch. Four temporal CSFs were measured for each eye, with one for each spatial frequency condition (1, 2, 4, and 8 cpd). The procedure described below was performed once for each eye (tested in a random order).

Stimuli for the Contrast Sensitivity measurements were organized into charts consisting of four bandpass-filtered Sloan letters arranged in a single screen-centered column (Supplementary Figure S1A). Each letter corresponded to one of four spatial frequency conditions, arranged in order of increasing peak spatial frequency from top to bottom (i.e., peak spatial frequency of 1 cpd for the top letter and 8 cpd for the bottom letter). The vertical center-to-center separation between adjacent pairs of letters was set to 1.5 times the height of the upper of the two letters. Each letter was centered inside a black frame that was twice the height and width of the individual letter (stroke width: 0.14°). The four frames were continuously visible on the chart.

Letters were selected by drawing four random letters without replacement from the full set of 26 letters of the English alphabet. Subjects therefore performed a 26AFC letter identification task in which they were instructed to read the four letters on the chart aloud, from top to bottom (Supplementary Figure S1A). Subjects were given unlimited time to make their responses, which were manually entered by the experimenter using a keyboard. Once a response was recorded for the last letter of a chart, it was immediately replaced by the next chart.
**Supplementary Figure S1.** Stimuli and data analysis used for the monocular contrast sensitivity task. (A) Each letter was shown at a variable contrast and temporal frequency determined by the quick CSF algorithm. Subjects were instructed to read the letters from top to bottom, and responses were manually entered by the experimenter. (B) Calculation of area under log tCSF (AULTCSF) and critical flicker frequency (CFF) from the temporal contrast sensitivity function. The AULTCSF serves as an estimate of overall contrast sensitivity and the CFF is the high-frequency cut off of the tCSF.

The contrast and temporal frequency levels for individual letters were controlled by the quick CSF (qCSF) Bayesian adaptive algorithm (Lesmes, Lu, Baek, & Albright, 2010) modified for 26AFC (Hou, Lesmes, Bex, Dorr, & Lu, 2015) and for an asymmetric log parabola, with 4 parameters: peak gain ($\gamma_{\text{max}}$), peak temporal frequency ($\omega_{\text{max}}$), low temporal frequency bandwidth ($\beta_{\text{lo}}$) and high temporal frequency bandwidth ($\beta_{\text{hi}}$). On each trial, the qCSF selected a combination of temporal frequency and contrast level to maximize the expected information gain over the parameters of the temporal CSF for each spatial frequency. Four independent instances of the qCSF algorithm were used to simultaneously estimate four temporal contrast sensitivity functions, one for each spatial frequency condition (1, 2, 4 and 8 cycles per degree). The temporal frequency and contrast levels were updated one chart at a time, and the selected stimulus properties for a given chart reflected responses from all preceding charts within a block of trials. Subjects completed two blocks of trials, one for each eye tested, consisting of 50 charts each (200 trials per block).

**Data Analyses**

From the Contrast Sensitivity functions, two values were calculated: the area under the log temporal contrast sensitivity function (AULTCSF), and the critical flicker frequency threshold (CFF) (Supplementary Figure S1B). The AULTCSF served as an estimate of overall contrast sensitivity, and was calculated using a trapezoidal integration between 1 Hz and the high-frequency cutoff,
defined as the highest temporal frequency with a log contrast sensitivity above 0 (analogous to visual acuity derived from the spatial CSF). This cut off served as an estimate of the CFF. For both AULTCSF and CFF, statistical comparisons were performed using a 4 x 2 x 2 mixed-model analysis of variance (ANOVA) using the Satterthwaite approximation for denominator degrees of freedom. Spatial frequency and viewing eye (dominant vs. nondominant) were within-subjects factors and refractive error group a between-subject factor.

**Results:**

A 3-way mixed ANOVA with two refractive groups (myopia or emmetropia), four SFs and two eyes (dominant or non-dominant) on AULTCSF showed a significant main effect of spatial frequency ($\text{F}(3,92.10) = 599.99, p < .001$), with lower temporal contrast sensitivity at higher spatial frequencies, consistent with previously reported results (Robson, 1966). There was no main effect of refractive group ($\text{F}(1,30.96) = 3.21, p = 0.08$) (Supplementary Figure S2), no significant difference in AULTCSF between the two eyes ($\text{F}(1,27.01) = 0.04, p = 0.85$), and no significant interactions among any of the three factors (all p-values >0.24). No correlation was found between the magnitude of the refractive error ($r_s(31) = -0.12, p = 0.49$) or axial length ($r_s(31) = 0.24; p = 0.17$) and AULTCSF. The interocular difference in AULTCSF was also not correlated with the interocular difference in refractive error (SE) ($r_s(31) = -0.10, p = 0.57$).

![Supplementary Figure S2. Mean AULTCSF values for subjects with myopia (red) and emmetropia (blue) as a function of the letter’s peak spatial frequency, averaged across the two eyes. Error bars show ± 1 standard error.](image)

The same 3-way mixed ANOVA on CFF also showed a significant main effect of spatial frequency ($\text{F}(3, 92.42) = 94.7, p < .001$). As expected, CFF values decreased with increasing spatial frequency (Supplementary Figure S3A). No main effect of refractive group was found ($\text{F}(1,31.13) = 3.75, p = 0.06$). A small negative correlation was found between the magnitude of the
refractive error and CFF, with higher myopes showing higher CFF values \((r_s(31) = -0.36, p = 0.04)\) (Supplementary Figure S3B). However, there was no correlation of CFF with axial length \((r_s(31) = 0.33, p = 0.06)\). Similar to the AULTCSF results, there was no main effect of viewing eye (dominant vs. non-dominant eye) \((F(1,30.33) = 0.60, p = 0.45)\). In addition, none of the interactions among the three factors reached significance (all p-values > 0.40).

**Supplementary Figure S3.** (A) Mean CFF values for subjects with myopia (red) and emmetropia (blue) as a function of the letter’s peak spatial frequency, averaged across the two eyes. Error bars show ± 1 standard error. (B) Correlation between refractive error (mean \(M\) for both eyes, D) and CFF values. Each scatter point represents one subject (average of 8 observations across four spatial frequencies and the two eyes tested), with red and blue scatter points corresponding to myopes and emmetropes, respectively.

**References**


Supplementary Appendix S2: Anisometropia, Astigmatism, and Contrast Sensitivity

Supplementary Figure S4. Correlation between contrast sensitivity (mean AULTCSF values) and binocular balance (left) and stereopsis thresholds (right). Each scatter point represents one subject, with red and blue scatter points corresponding to myopes and emmetropes, respectively. Correlation values shown are Spearman’s rank correlation coefficient.

Supplementary Figure S5. Correlations comparing either binocular balance (top row) or stereopsis thresholds (bottom row), with the level of anisometropia, anisoastigmatism, or astigmatism (in columns from left to right). Anisometropia was calculated as the absolute interocular difference in SE (D), anisoastigmatism was calculated as the absolute interocular difference in cylinder power (D), and astigmatism was calculated as the cylinder power (D) averaged across eyes. Each scatter point represents one subject, with red and blue scatter points corresponding to myopes and emmetropes, respectively. Correlation values shown are Spearman’s rank correlation coefficient.