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Demonstrating the temporal modulation transfer function

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Abstract. A 120-frame movie, which can be downloaded from specified web sites, allows an observer to see the qualitative form of his or her temporal modulation transfer function. Results collected from two of the authors are presented.

The spatial contrast sensitivity function is a measure of the extent to which each spatial frequency of a sinusoidal grating is transferred by the visual system (see De Valois and De Valois 1988). Sensitivity is highest for spatial frequencies close to 5 cycles deg^{-1} and falls off at lower and higher frequencies (Blakemore and Campbell 1969). Campbell and Robson (1968) published a chart which allows an observer to see the qualitative form of his or her spatial modulation transfer function (MTF). It is a field of vertical sinusoidal bars whose spatial frequency increases from left to right and whose contrast increases from top to bottom. The lower, high-contrast part of the field is visibly striped, whereas the upper, low-contrast part appears to be spatially uniform. If sensitivity were the same at all spatial frequencies, then the line separating the visible from the invisible region would be horizontal. In fact, however, the line is bowed upwards at spatial frequencies around 5 cycles deg^{-1}, showing the lowest threshold (highest sensitivity) at this frequency. The line slopes downward for lower and higher frequencies, delineating the fall off in sensitivity for coarser and finer stripes.

The temporal contrast sensitivity function is a measure of the extent to which each temporal flicker rate of a spatial uniform field is transferred by the visual system. For the light-adapted eye, sensitivity is generally highest at temporal frequencies in the range 5 – 10 Hz and falls off at lower and higher temporal frequencies (de Lange 1952; Kelly 1961; Snowden et al 1995).

We have devised a movie which allows an observer to see the qualitative form of his or her temporal MTF. This movie, which is the temporal analog of Campbell and Robson's spatial chart, consists of an array of small, sinusoidally flickering square tiles, and resembles a graph in which $x =$ temporal frequency and $y =$ contrast. One frame of the stimulus is shown in figure 1, and the time sequence is shown schematically in figure 2. In each successive column from left to right of figure 1 the flicker rate increases in approximately half-octave steps. In the bottom row of tiles the contrast is high, and decreases in each successive higher square. The whole tiled area appears to be divided into a lower, high-contrast region in which the flicker is visible and an upper, low-contrast region which appears to be static, since the flicker is too fast or too low in contrast to be resolved. If sensitivity were the same at all temporal frequencies, then the line separating the visible from the invisible region would be horizontal. In fact, however, the line is bowed upwards at temporal frequencies around 5 – 10 Hz, showing the lowest threshold (highest sensitivity) at these frequencies. The line slopes downward for lower and higher temporal frequencies, indicating the fall off in sensitivity to higher and lower flicker rates.

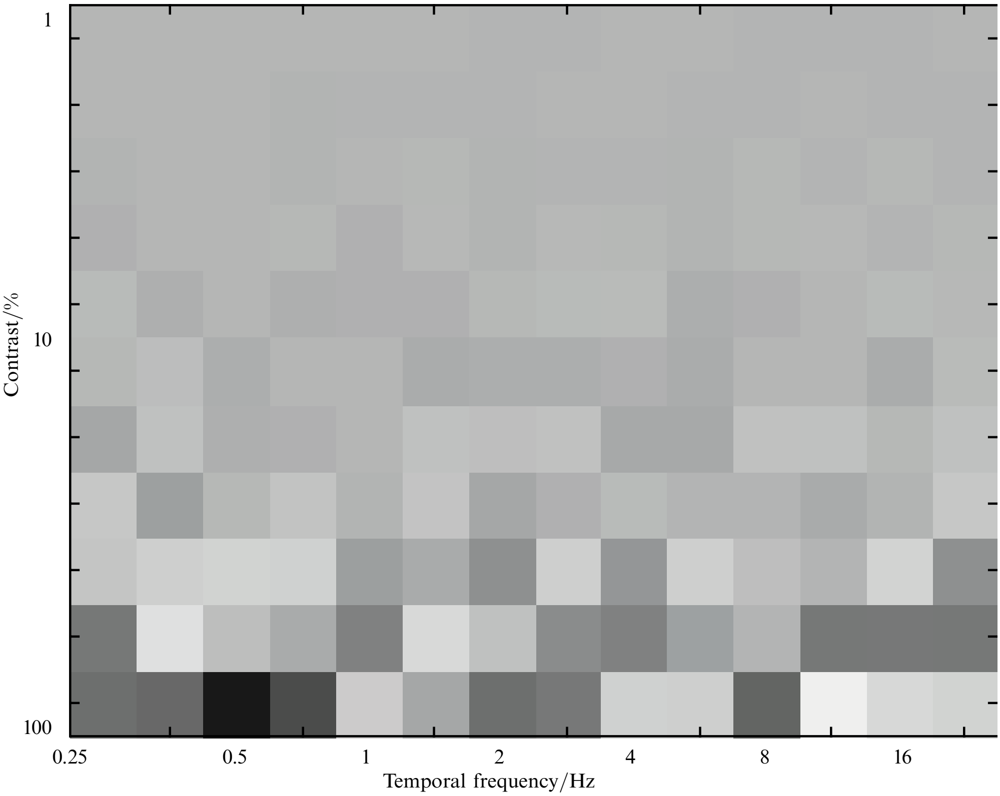

Figure 1. Snapshot of the stimulus. Temporal frequency increases to the right and contrast increases downwards. The screen was divided into 14×12 coarse pixels, and each pixel varied sinusoidally over time. All pixels within a column flickered at the same frequency, but with randomized phases. Flicker threshold will lie perhaps halfway up each column: the exact height depends crucially upon the temporal frequency.

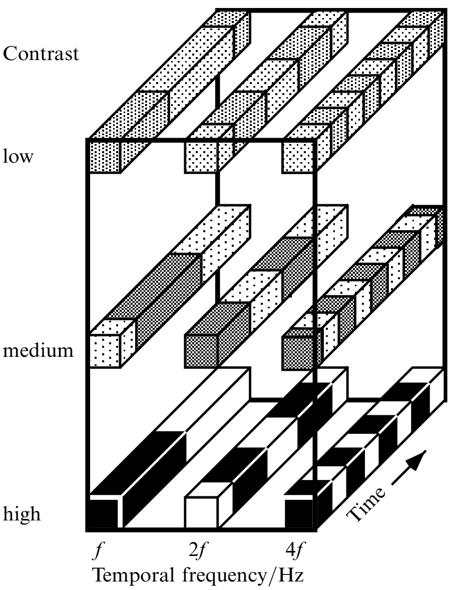

Figure 2. The time course of some sample pixels from figure 1 is shown; flicker is depicted as square wave for simplicity, but was actually sinusoidal.

The stimulus was implemented as a 120-frame movie in Matlab 5.0 on the Macintosh, and can be downloaded from either of these web sites:

http://www-psy.ucsd.edu/~sanstis/TMTF.html

http://www.ski.org/CWTyler_lab/CWTyler/TMTFDemo/TMTFDemo.html

The file is also available on the *Perception* web site:

http://www.perceptionweb.com/perc0599/anstis.html

and will be archived on the *Perception* annual web site CDRom.

The Matlab source code, written by Chien Chung-Chen, can also be downloaded from these pages.

When the program is run, the movie runs for 60 s. There are fourteen temporal frequencies ranging from 0.25 to 16 Hz and twelve levels of Michelson contrast ranging from 0.01 to 1.0 (depending on the monitor settings).

The picture size is limited to 6 cm wide × 5 cm high; to make the picture bigger would require re-writing the program in some faster format such as C or assembly language. We have prepared two versions of the stimulus. In the first version all the tiles within a column (all flickering at the same frequency) were in phase. This generated undesirable spatiotemporal beat frequencies in the form of vertical lines several columns wide

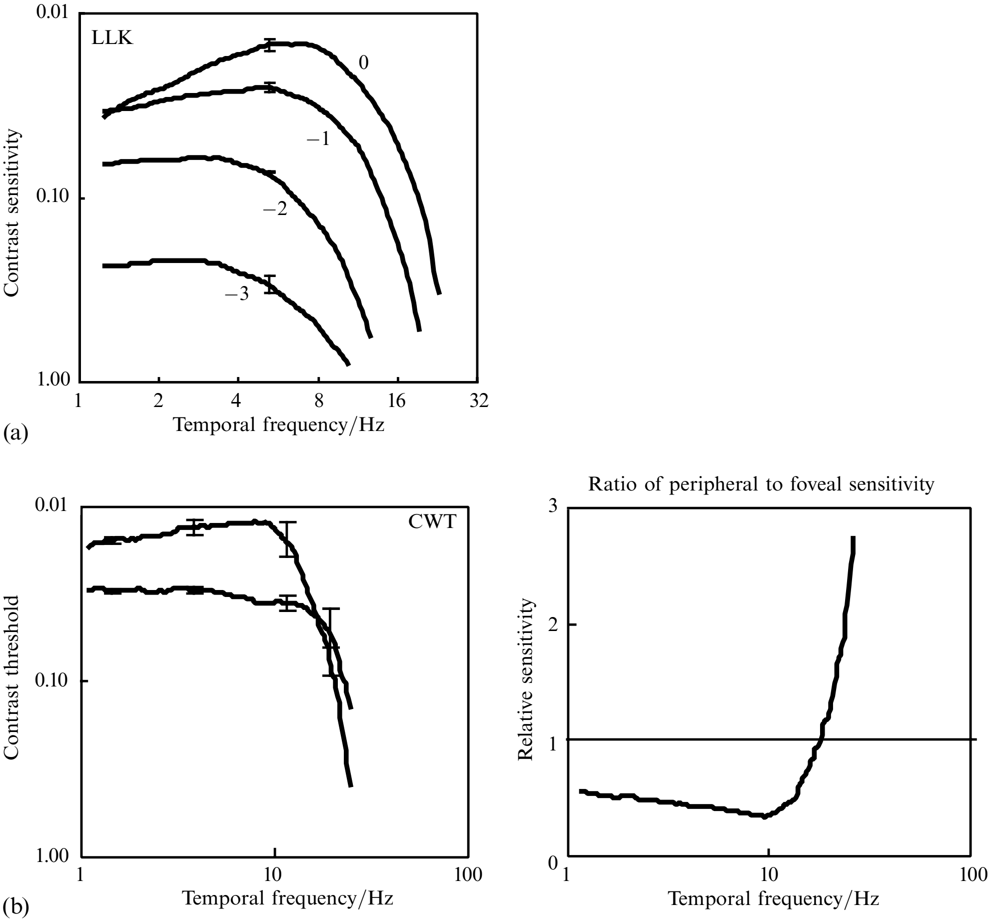

Figure 3. Results from two trained subjects (mean of three trials). (a) Darkening the stimulus with neutral density filters moved the MTF curves down and to the left, showing the increasing sluggishness of the dark-adapted visual system. Observer: LLK. (b) Peripheral viewing of the flickering stimulus degraded sensitivity to low temporal frequencies but enhanced it for high frequencies. Observer: CWT.

which oscillated horizontally back and forth and changed in width rhythmically as they did so. We removed these beats by randomizing the phase of each square tile. As a result the spatial array at any given time was a dense array of grey tiles of random luminance levels.

Figure 3 shows the results, which were collected from two of the authors. The observer viewed the monitor screen from a distance of 57 cm and drew a continuous line with a felt-tipped pen on a piece of transparent acetate which was taped to the screen. This line divided the screen into a lower region in which flicker was visible and an upper region in which no flicker was visible. This line defined the observer's temporal MTF. The coordinates of the line were encoded later by the experimenter.

Figure 3a shows the effects of dark adaptation: Viewing the stimulus through neutral density filters of 1.0 or 2.0 log units moved the MTF curves down and to the left, showing the increasing sluggishness of the dark-adapted visual system. Figure 3b shows the effects of peripheral viewing. When the observer fixated on a point located 4 deg above the center of the flickering pattern, his sensitivity to low temporal frequencies was reduced but his sensitivity to high temporal frequencies was improved.

Drawing each MTF line took a trained observer only about 10 s, suggesting that this technique might be suitable for teaching a student laboratory class. Analyzing the data by scanning them into the computer and passing them sequentially through Photoshop, Macdraw Pro, DataThief, and Excel took longer.

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