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Temporal processing in very low vision

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Abstract Visual temporal frequency discrimination (TFD) capacities of four adults with very low vision (VLV) were assessed. Full-field flicker was generated by placing a 5x5 red LED array against a translucent eyepatch that served as a diffuser. Temporally modulated phase-randomized sine wave stimulus pairs (standard and test frequencies) were presented monocularly using a 2IFC procedure. Discrimination was tested at standard frequencies ranging between 0.75 and 57 Hz; TFD difference thresholds (ΔF) for the ten standard frequencies were estimated from maximum likelihood fits of Weibull functions. ΔF was a constant or nearly constant proportion of F throughout the assessed range. These results show conclusively that TFD judgements can be rendered by those with simulated and actual VLV. Temporal coding of full-field light modulation has the potential to optimize a neglected sensory channel in individuals with VLV.

Key words Low vision; blindness; orientation and mobility; temporal processing; flicker

Introduction Visual impairment spans a wide range of visual capability, from moderate vision loss, despite best correction, to total loss of light sensitivity. Most individuals with low vision have significant usable vision which, with appropriate visual aids, allows them to perform most tasks that normally require vision, such as reading and locomotor navigation (although performance may be compromised). At the low end of the low vision spectrum are individuals who may be able to discriminate light from dark, but have little or no pattern vision. Clinically, these individuals, whose vision is referred to here as 'very low vision' (VLV) have capabilities that are typically described as 'hand motion', (rudimentary) form/shape perception, light projection, and/or light perception. Functionally, those with very low vision rely predominantly on nonvisual sources of information for mobility.

The purpose of this study was to assess temporal frequency discrimination in a sample of adults with VLV. Of particular interest was whether

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VLV may be adequate to support the use of flickering lights as a substitute for spatial distributions of light. If so, then flicker patterns representing nearby objects, e.g., dropoffs or obstacles in one's path, could conceivably be generated for use in orientation and mobility. That is, representational flicker patterns might be coded to present electronically gathered information to the traveler, to augment existing orientation and mobility cues. An effective substitution would depend on the individual's performing an internal temporal-to-spatial translation to circumvent the spatial vision deficit.

Temporal frequency discrimination (TFD) in human vision was evaluated some years ago by Mandler¹ and Mandler and Makous.² That work led to the conclusion that there are as few as two to three temporal filters whose outputs are compared in order to perform the frequency discrimination. Additional empirical investigations of temporal frequency sensitivity and/or temporal frequency discrimination have been conducted more recently.³⁻⁷ Most of the reports since Mandler support his initial findings (e.g., Hammett and Smith³ and Hess and Snowden⁴); work by Snowden and Hess⁵ examined near-foveal capacities and hypothesized three filters, whereas Waugh and Hess⁶ offered evidence that as few as one channel may account for peripheral capacities.

A small number of studies have evaluated TFD in participants with vision disorders. Hess and Plant,⁸ for example, compared the temporal frequency discrimination responses of seven adult patients with mild visual acuity loss (caused by optic neuritis or multiple sclerosis) with those of unaffected adults. In general, differences were found in the temporal frequency processing capabilities of the patients versus the normally sighted participants, including a lower peak and cutoff in the temporal frequency discrimination function. While the study used grating stimuli (0.2 and 2 c/deg) and is thus not strictly comparable to the full-field flicker presentation used here, it demonstrated that even modest losses in vision may result in distinct changes in temporal processing.

The present research investigated the temporal processing variables which were thought to be most relevant to low vision and to have the potential to augment functioning. Temporal frequency discrimination was emphasized because the frequency of a light stimulus can be controlled and manipulated relatively easily and might therefore ultimately be harnessed for practical purposes. Measurements were also made of temporal contrast sensitivity (TCS) to evaluate the observers' sensitivity to flicker. Full-field flicker, rather than flash stimuli restricted in spatial extent, was adopted in order to heighten the probability that light would fall on all functioning portions of the retina. This approach further ensured that TFD could be investigated in VLV arising from a wide range of causes, e.g., in disorders associated with loss of central vision as well as in those with oculomotor disorders such as fixation or alignment anomalies.

Materials and methods

PARTICIPANTS Four adults with very low vision served as subjects and were compensated at a rate of \$10.00 per hour. Recruitment aimed to encompass a range of individuals whose (self-reported) vision fit the operational definition of VLV set forth above; for example, one participant (JS1)

had a Snellen acuity of 20/4000 (measured for purposes of a different study). Complete or partial datasets were also obtained from several adults with normal vision, e.g., EL2, in whom VLV was simulated by lid closure during testing. It should be noted that the testing also involved the wearing of a light-diffusing eyepatch (see Procedures below).

APPARATUS A computer, a digital-to-analog converter (DAC), and a voltage-to-current driver were used to activate a 5x5 red (660 nm) array of high-intensity light-emitting diodes (LEDs). The array was attached to the exterior of a diffusing eyepatch (placed over the observer's tested eye). The eyepatch assembly consisted of a translucent plastic lens with a foam rubber baffle (for a description, see Fuhr⁹). The resulting configuration generated stimuli of uniform full-field illumination.

STIMULI To produce flicker, a sine wave was sampled at a frequency inversely proportional to the stimulus frequency (resulting in a minimum of 18 samples per cycle for 57 Hz, the highest standard frequency used, and a maximum of 1368 samples per cycle for 0.75 Hz). This sampled waveform was output through the DAC at a rate of 1000 points per second. Contrast here refers to the peak amplitude of the sine wave of the stimulus divided by its mean luminance (Michelson contrast). Temporal contrast sensitivity (TCS) was defined as the reciprocal of the contrast needed to detect the modulation.

PROCEDURES Signed informed consent was obtained from all participants; all procedures had received institutional review board approval and were in accordance with the tenets of the Declaration of Helsinki. A brief questionnaire was used to gather data from participants with VLV; items pertained to the characteristics and duration of their vision loss and on use of visual cues in mobility. Table 1 summarizes questionnaire data from each of the participants with VLV. Psychophysical data collection followed.

TEMPORAL FREQUENCY DISCRIMINATION MEASUREMENTS Temporal frequency discrimination was assessed at ten selected standard frequencies of 0.75, 1.5, 3, 4, 8, 16, 20, 32, 44, and 57 Hz, using the method of constant stimuli (MOCS), in which the difference between the standard and test frequency was varied randomly from trial to trial. Phase-randomized temporally modulated sine wave stimulus pairs, each comprised of the standard and a test frequency, were presented monocularly using a procedure in which the participant evaluated two stimuli presented sequentially and selected either the first or second as flickering faster (two-interval forced choice). Mean luminance was set individually at levels comfortable for each participant. Most participants were comfortable with relatively low luminance levels; only participant JS1 tolerated 90 cd/m² (see Fig. 1 for details). The ten test frequencies exceeded the standard in equal logarithmic steps. The test frequencies (each paired with the standard) were presented in random order within blocks of ten trials each. The participant pressed either of two buttons to select the apparently faster flicker rate within each trial pair. Computer-generated verbal feedback was provided after every response, indicating whether the selection had been correct or incorrect.

TABLE I. Participant Information.

<i>Participant code</i>	<i>Etiology</i>	<i>Functional vision</i>
AM2	Ischemic optic neuropathy	Reads highly enlarged, high-contrast text. Uses cane.
DN1	Diabetic retinopathy	Cannot read text. Uses cane.
NK1	Congenital cataracts, glaucoma, detached retinas	Light, shadow, color sensitivity. Uses cane.
JS1	Congenital micro-ophthalmia and corneal opacity	Reads braille and highly enlarged text. Uses cane.
EL2	Not applicable	Normal

TEMPORAL CONTRAST SENSITIVITY MEASUREMENTS Temporal contrast sensitivity was assessed at the same standard frequencies that were used to gather TFD data, using the method of adjustment (MOA) in which the contrast of the stimulus at each standard frequency was placed under the control of the participant, who adjusted it until reaching the threshold of visibility. This technique was used to obtain approximate, but consistent, TCS threshold values at each of the ten standard frequencies.

Results Temporal frequency discrimination difference thresholds for each standard frequency were estimated from maximum likelihood fits of Weibull functions.^{10,11} Each of the ten TFD threshold estimates generated for each participant was calculated using a minimum of 50 observations. Threshold was defined as the frequency associated with a performance level of 75%.

Figure 1 shows ΔF , the TFD difference threshold, as a function of standard frequency for four participants with VLV (NK1, AM2, JS1, and DN1) and one participant in whom VLV was simulated (EL2). The TFD thresholds increased as a roughly exponential function of standard frequency (that is, roughly linearly on these log-log plots). Four data points are missing, either because threshold could not be measured at that frequency (NK1 and DN1 at 57 Hz) or because bracketing yielded psychometric functions with inappropriate variability (AM2 at 44 Hz, DN1 at 8 Hz).

Figure 2 presents the same data as difference thresholds relative to the standard frequency. ΔF was either a constant proportion of F throughout the assessed range or declined slightly with increasing frequency.

The ability to discriminate frequencies varied widely, both within and across participants, although the performance across participants was similar in form. The participants with the best discrimination required only approximately a 10% difference in frequency, whereas those with the poorest discriminations required 100%. Interestingly, one of the participants with VLV (JS1) had the best temporal frequency discrimination overall.

Figure 3 shows temporal contrast sensitivity as a function of standard frequency for each of the five observers. When considering these data in relation to TFD, note that TCS was lowest in the three observers with the worst discrimination performance and highest in the two observers with the best discrimination performance. Participant JS1, whose discrimination performance was the best and who has VLV, had high temporal contrast sensitivity.

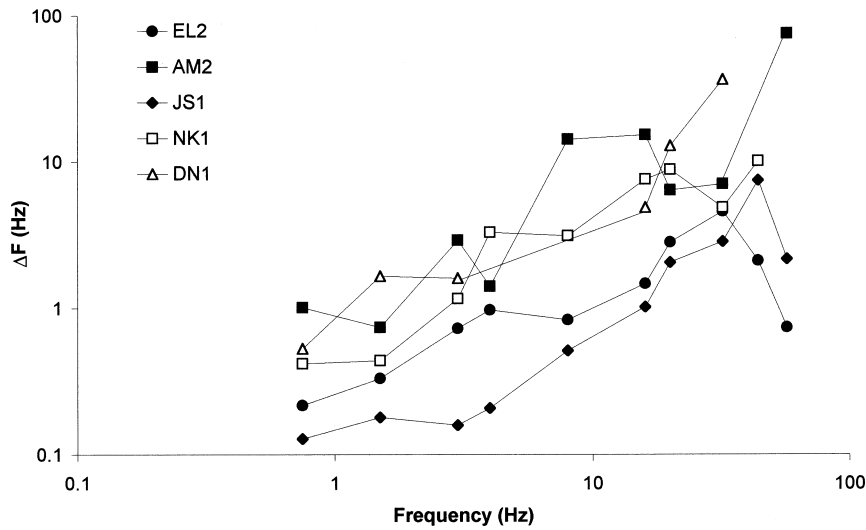


Fig. 1. Difference thresholds for temporal frequency discrimination. Mean luminance was 18 cd/m² for EL2, 19 cd/m² for AM2, NK1, and DN1, and 90 cd/m² for JS1. Contrast was 0.68 for EL2, 0.69 for AM2, NK1, and DN1, and 0.94 for JS1.

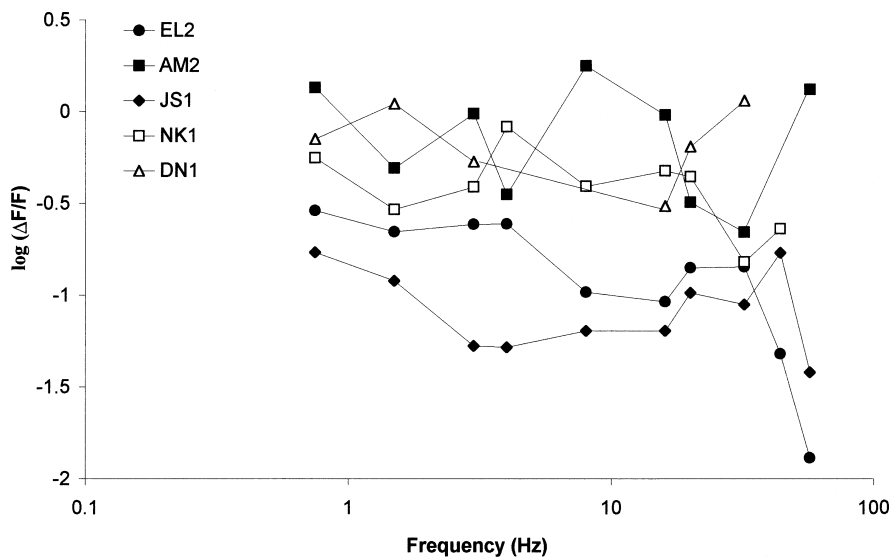


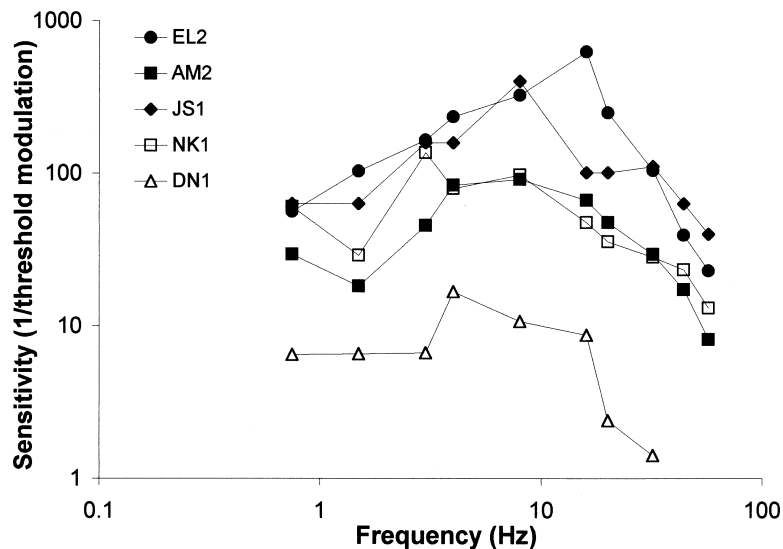
Fig. 2. The same data as Figure 1, plotted as relative difference thresholds.

Discussion This research demonstrates that TFD and TCS judgments can be rendered by adults with simulated and actual VLV. The TFD data obtained here agree generally with those of Mandler,¹ who studied adults with normal vision, in that ΔF increased with frequency. It is possible that the observers in the present study were able to make some discriminations on the basis of differences in apparent modulation rather than frequency (see, e.g., Magnussen and Bjorklund¹²).

The strength of this research is its data-supported identification of a possible new way to tap into the capacities of people with very low vision. The evidence from each of the two temporal measures is best considered in combination, e.g., the best TFD performers were those with the best TCS. Both TFD and TCS, therefore, can be regarded as new tools/features for possible exploitation in mobility aids.

These results support the idea that temporal coding of full-field light modulation has the potential to optimize a neglected sensory communication channel in individuals with VLV. The data constitute preliminary evidence that temporal cues may be a useful source of visual information for certain individuals who can respond to temporal visual input, but who cannot resolve

Fig. 3. Temporal contrast sensitivity measurements for the five subjects using MOCS.



spatial patterns. For people with VLV, controlled temporally coded visual input may be adequate to serve as a gross but salient substitute for spatial light distributions. Potential applications of the results of this research include development of an optical device which could be used to exploit temporal vision and a diagnostic procedure to evaluate the possible efficacy of such a device. By presenting enhanced temporal cues, as an adjunct to other salient inputs used by individuals with VLV, the potential thus exists to augment visual functioning, for example, to increase safety and improve travel efficiency during orientation and related mobility.

References

- 1 Mandler MB. Temporal frequency discrimination above threshold. *Vision Res* 1984;24(12):1873-1880.
- 2 Mandler MB, Makous W. A three channel model of temporal frequency perception. *Vision Res* 1984;24(12): 1881-1887.
- 3 Hammett ST, Smith AT. Two temporal channels or three? A re-evaluation. *Vision Res* 1992;32(2): 285-291.
- 4 Hess RF, Snowden RJ. Temporal properties of human visual filters: number, shapes and spatial covariation. *Vision Res* 1992;32(1): 47-59.
- 5 Snowden RJ, Hess RF. Temporal frequency filters in the human peripheral visual field. *Vision Res* 1992;32(1):61-72.
- 6 Waugh SJ, Hess RF. Suprathreshold temporal-frequency discrimination in the fovea and the periphery. *J Opt Soc Am A* 1994;11(4):1199-1212.
- 7 Raninen AN, Rovamo JM. The effects of temporal noise and eccentricity on flicker sensitivity. *Invest Ophthalmol Visual Sci* 1997; 38:S381.
- 8 Hess RF, Plant GT. Temporal frequency discrimination in optic neuritis and multiple sclerosis. *Brain* 1985;108(3):647-676.
- 9 Fuhr PS, Hershner TA, Daum KM. Ganzfeld blankout occurs in bowl perimetry and is eliminated by translucent occlusion. *Arch Ophthalmol* 1990;108:983-988.
- 10 Maloney LT. Confidence intervals for the parameters of psychometric functions. *Percept Psychophys* 1990;47(2):127-134.
- 11 Watson AB, Robson JG. Discrimination at threshold: labelled detectors in human vision. *Vision Res* 1981;21:1115-1122.
- 12 Magnussen S, Bjorklund RA. The perception of suprathreshold sinusoidal flicker measured by light- and dark-phase matching. *Vision Res* 1979;19(3):335-338.