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LETTER TO THE EDITORS

VEP ASSESSMENT OF VISUAL FUNCTION*

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In a recent Research Note, Regan (1980) has reviewed the use of stimulus sweep methods for rapid visual assessment by the visual evoked potential. These methods involve the continuous recording of electrical brain response while sweeping through a range of values of a stimulus parameter. Regan (1973, 1975, 1977) has pioneered the development of techniques for sweeping refractive power, contrast and size of stimulus elements which are potentially of great utility for the rapid assessment of a variety of visual functions. Regan's (1980) Research Note, however, points out a variety of pitfalls in the general application of such techniques, specifically questioning a version of the sweep technique that we have developed for acuity estimation (Tyler *et al.*, 1979).

Our electronic sweep technique allows spatial frequency to be swept over a 1000:1 range (we have used a 100:1 range) with constant luminance and contrast, where optomechanical devices such as those described by Regan are limited to a range of about 10:1.

Regan's approach to sweeping stimulus size emphasizes the evoked potential amplitude as a function of check size, since checkerboard stimuli give the largest evoked potentials. He has also developed a method of measuring contrast threshold at particular spatial frequencies by sweeping stimulus contrast (Regan, 1975). Our method is specifically designed for the electrophysiological measurement of grating acuity. This is obtained by linear extrapolation to zero voltage on a *linear* spatial frequency axis. This method is based on a synthesis of the Regan (1973) sweep method and the Sokol (1979) extrapolation method, in which the amplitude of discrete evoked potentials is assumed to be a negative linear function of spatial frequency. The extrapolation provides a measure of visual resolution up to the point in the visual pathway at which the evoked potential is generated, and is subject to the limitations of the recording technique. For these reasons we have called it electrophysiological acuity rather than identifying it with behavioral acuity. Behavioral acuity may itself be limited by the inadequacies of behavioral techniques, and the two methods provide complementary information about the visual capabilities of the patient.

We applied the linear extrapolation method of electrophysiological acuity measurement to the assessment of refractive error and the assessment of monocular acuity. The data thus obtained showed good agreement with behavioral data measured under the same stimulus conditions. In other cases, such as interocular comparison in patients with amblyopia, our approach is essentially a modification of Regan's checkerboard technique, using sinusoidal grating stimuli having a purer spectral composition.

Amplitude insensitivity

Regan (1980) raises the issue that amplitudes of pattern evoked potentials vary across observers, electrode location and retinal region of stimulation, which would make a diagnosis based on amplitude unreliable. However, the linear spatial frequency extrapolation method is insensitive to amplitude changes *per se*, and the intercept will also be unaffected by variations in electrode resistance. Thus, if the amplitude (a) is a negative linear function of spatial frequency (s) at high spatial frequencies, the equation describing the function is:

$$a = k(s_0 - s)$$

where s_0 is the spatial frequency intercept. It is clear that the slope of this function (k) can in principle vary independently of the intercept (s_0). As an example, we presented stimulus fields of differing sizes. Although the response was much greater for the larger stimuli, the intercept was at the same spatial frequency in all cases (see Fig. 3B, Tyler, *et al.*, 1979). Thus variations in VEP amplitude do not inherently affect the frequency at which the extrapolated slope intersects zero voltage.

In practice we have shown that the intercept is relatively independent of changes in amplitude (and hence of slope) due to stimulus field size. It may not be so independent of electrode position, but we would suggest that as long as the electrodes are positioned near the primary visual cortex they will have a high probability of picking up some activity from the high acuity region of the cortex. An additional precaution would be to obtain the acuity limit simultaneously

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from several electrodes and to accept the highest value.

Temporal insensitivity

Regan (1980) re-emphasizes the point he made in a previous publication (Regan, 1978), that the amplitude of the synchronous VEP depends markedly on the temporal frequency of stimulation and recording. We have also made this point (Tyler *et al.*, 1978), and in addition have shown that at many temporal frequencies of stimulation there are multiple-peaks in the response each tuned to different spatial frequency.

Despite these variations, the linear extrapolation method appears to be surprisingly accurate under a wide range of conditions (Tyler *et al.*, 1979). For most conditions the extrapolated acuity limit falls within a factor of two from the psychophysical acuity, corresponding to a maximum discrepancy of two lines on a Snellen chart. In terms of temporal frequency, our data from six observers (three published in Tyler *et al.*, 1978) show that the high spatial frequency limit of the synchronous VEP is approximately constant up to a stimulation rate of 30 reversals per sec (rps) (30 Hz recording rate) and follows a spatio-temporal reciprocity function from 30 to 100 rps (Tyler *et al.*, 1978b). Thus the extrapolated acuity should be relatively independent of temporal frequency up to 30 rps.

In this connection, we note that the signal-to-noise ratio is typically considerably larger in the 20–30 rps range than the lower frequency range (e.g. 6 rps) described by Regan (1977).

Phase insensitivity

The method of synchronous recording that we have suggested for clinical applications is also insensitive to response phase or polarity reversal of the response, which is an important prerequisite discussed by Regan (1980). The synchronous response is detected by means of a 8-bin commutating filter with a bandwidth of less than 1 Hz, full-wave rectified and smoothed to produce the continuous output for the swept amplitude plot. The rectification and smoothing procedure measures only the amplitude of the response, and ensures that the amplitude is unaffected by phase changes in the response. Details of the synchronous filter are published elsewhere (Tyler *et al.*, 1978).

A related question that has been raised in personal communication with other investigators concerns the proportion of the response occurring at the second harmonic of the stimulation rate (i.e. at the stimulus reversal rate). We have found that at high stimulation rates (above 10 Hz or 20 rps) and high spatial frequencies (above 5 c/deg) the response is effectively sinusoidal with the second harmonic accounting for at least 90% of the synchronous power (i.e. the main response is at the stimulus reversal rate). Similar results have been reported by other investigators (Campbell and Maffei, 1970; Freeman and Thibos, 1975). Under these conditions our synchronous recording method measures essentially the entire neural response reaching the scalp recording site.

A method of averaging graphs

There is an implication in Regan's paper that we have advocated the use of a single sweep as an adequate measure of visual function. In fact, the reverse is the case, as we always present at least two sweeps to show the replicability of the responses. We merely mentioned that the full range of stimuli can be presented in a single sweep. Although Regan's "graph averaging" method is useful where the response is non-stationary, our replications show that the responses usually remain within about $\pm 10\%$ of the same amplitude across replications separated by time intervals of a few minutes. Where the responses show rapid variability, such as recording from an inattentive infant, the sweep method is less suitable. In such cases, other techniques may need to be developed.

Nature of the pattern evoked potential

In agreement with Spekreijse (1966) and Spekreijse *et al.* (1973), Regan (1980) makes a distinction between "local luminance" evoked potentials and "genuine contrast" evoked potentials, although the precise definitions of these terms are obscure. He states that "in principle, large amplitude pattern evoked potentials might be recorded from subjects with no behavioral visual acuity at all". However, large pattern-specific responses can be obtained at temporal frequencies where essentially no luminance response is recorded (Tyler *et al.*, 1978; Regan, 1973, 1978). We have suggested that luminance responses do not contribute to pattern responses beyond 0.5–1 c/deg.

We feel that, in principle, the presence of a response to a pattern stimulus implies that the visual system contains elements capable of resolving the stimulus. The value of the measurement of acuity electrophysiologically is that one can make an objective determination of the resolution capability of the visual pathway even if the patient is unable to respond behaviorally. This may provide a basis for treatment of the visual problem behaviorally (e.g. in hysterical visual losses) if the electrophysiological acuity is less affected than would be indicated by behavioral response. Electrophysiological acuity may also be a useful index in monitoring the effects of eye surgery in children too young to give reliable behavioral indices. As mentioned above, the electrophysiological estimate, although objective, may still be an underestimate due to limitations of the recording technique or ocular conditions such as pronounced nystagmus. This does not undermine its value in cases where the electrophysiological acuity is greater than the behavioral acuity.

Conclusion

Although Regan raises many valuable points concerning the limitations of acuity measurement by sweep VEP techniques, we believe that the linear

extrapolation method described by Tyler *et al.* (1979) overcomes most of them, and constitutes a useful approach to the clinical measurement of visual acuity.

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