A BASIS FOR EVOKED POTENTIAL ASSESSMENT OF CERTAIN VISUAL FUNCTIONS

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**Key Words:**
- Visual Evoked Potentials
- Visual Test
- Test Battery
- Visual Acuity
- Contrast Sensitivity
- Spatial Frequency
- Electrophysiology

**Abstract:** Evoked potential recording is a technique for recording electrical brain responses from scalp electrodes so as to assess human visual functions objectively. This report describes two evoked potential stimulators and methods for testing visual acuity and visual contrast sensitivity. These two electronic devices enable true contrast responses to be distinguished from responses to changes in local light intensity. This is achieved by dissociating the direction of contrast change from the direction of intensity change. The devices also
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all of different stimuli to be randomly interleaved under computer control. This procedure improves measurement accuracy by combining interleaving (to combat slow changes of the evoked potential with time) with signal averaging (to combat the unfavourable signal-to-noise ratio). Pattern and contrast evoked potentials are similar to those generated by the relatively inflexible optical technique, and the major EP component to pattern appearance is shown to be a true pattern response of the human visual pathway.
(b) LIST OF RESEARCH OBJECTIVES AND STATEMENT OF WORK

Since evoked potential recording is a means of objectively assessing specific visual functions that are relevant to flying and hence of assessing workload, the evoked potential technique has been proposed as one element in a test battery. However, a number of specific experiments must be carried out before fully satisfactory evoked potential tests can be defined. In order to carry out these essential experiments, it is necessary to develop new forms of visual stimulation, and to establish new forms of analysis procedure. These analysis methods (involving developments of the "simultaneous stimulation" and interleaving techniques) are aimed to combat the effects of evoked potential variability and non-stationarity.

The experimental evoked potential (EP) research that was proposed under this grant fell under the following four headings: (1) Assessment of stereo vision; (2) Assessment of simple visual acuity; (3) Assessment of contrast sensitivity at medium and low spatial frequencies. Distinction between contrast evoked potentials and local luminance evoked potentials produced by pattern stimulation; (4) Methods for measuring the conduction speed of visual signals. For reasons given below only about 50% of the proposed work has been completed during the grant period (though considerably less than 50% of the total funds have been expended).
Reason why 50% of the research aims were not achieved during the one-year grant period

Due to some initial delay in establishing funding, a suitable post-doctoral assistant accepted another post, and a well-qualified graduate student had to be started on another project. I advertised the position in scientific journals and received about 30 applications from candidates interested in this type of research. I took up references for almost all of these applicants, and interviewed several. Unfortunately, none of the candidates met the demanding technical (electronic) and scientific demands of the project. Rather than appoint assistants whose abilities to meet the demands of this project were in any doubt, I continued to search for adequately qualified and capable assistants. Although assistants were found who were well qualified for other of our projects, unfortunately none were found suitable for this project during the period of the grant. In order to ensure that progress was made during the period of the grant, I undertook the technical and experimental work myself without assistants using equipment mostly borrowed from other projects and researchers. Although about 50% of the aims stated in the grant application have been achieved, due to lack of assistance, progress has been much less than I had planned and envisaged. However, expenditure has been much less than 50% of the total sum allowed, mainly because I did not intend to purchase the larger items of equipment until full achievement of the experimental aims could be confidently envisaged.
Aims 2 & 3: Assessment of visual acuity; Assessment of contrast sensitivity at medium and low spatial frequencies and distinction between contrast EPs and local luminance EPs produced by pattern stimulation.

The major problem in interpreting evoked potentials produced by pattern stimulation is to distinguish between evoked potential components that are genuinely produced by contrast stimulation and components produced by local luminance changes (i.e. local flicker). A major proportion of all papers on pattern evoked potentials do not confront this problem. Consequently, there is a serious hidden defect in very many papers on pattern evoked potentials: they cannot be clearly interpreted since they confound contrast responses with local luminance response.

Examples of this confounding include the following findings:
(a) Richards and I showed that although, as expected, evoked potential amplitude is attenuated by blurring a pattern of small checks, blurring a pattern of larger checks can increase evoked potential amplitude\(^1\);
(b) I showed that high spatial frequencies are "tuned" to a temporal repetition frequency about 8 cycles per second whereas low spatial frequency responses are tuned to a frequency of about 17 cycles per second.\(^2\)

Thus, the shape of the grating modulation transfer function depends on the choice of temporal frequency.

Figure 1 illustrates the rationale of a test that has been developed that can counter this problem (see also Appendix 1). The test is to introduce a small luminance change into the stimulus and to compare evoked potentials recorded under the following two stimulus conditions: (a) when contrast and luminance increase simultaneously; (b) when contrast increases
while luminance decreases. This test can disentangle two constituents of pattern EPs. We have designed and constructed two visual stimulators that enable this test to be carried out and also enable the test to be combined with routine assessment of contrast sensitivity and visual acuity. (3) One stimulator generates checkerboard patterns, and the other stimulator generates sinewave grating patterns. The sinewave grating pattern stimulator also includes a multi-stimulus interleaving device that improves accuracy by reducing the effect caused by slow changes of the EP with time.

Appendix 2 contains a technical description of the variable-contrast checkerboard stimulus generator and Appendix 3 contains details of the variable-contrast sinewave stimulus generator and random interleaving computer programme.

In order to dissociate responses to contrast (pattern) from responses to changes in local luminance, it is necessary to separately record EPs to the appearance and disappearance of pattern. We first described pattern appearance and disappearance responses in 1969 (4,5) using an optical checkerboard-mirror stimulator. Figures 2, 3 and 4 show that our electronic checkerboard stimulator

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**Figure 1.** Test to distinguish between evoked potential components genuinely due to contrast change and evoked potential components due to changes in local luminance. See Appendix 1.
produces pattern appearance and disappearance EPs of similar form to those obtained by the optical technique.

![Diagram showing left and right eye responses to appearance and disappearance of a stimulus pattern](image)

**Figure 2.** The appearance and subsequent disappearance of a stimulus pattern produce two quite distinguishable responses that have different cortical origins, different dynamics, different binocular summation and are differently affected by spatial frequency or check size. The appearance response consists of three components of which only C1 originates in striate cortex. Positive deflection downwards. Optical stimulator.

Components C1, C2 and C3 of the appearance EP are marked, and the pattern disappearance EP is also marked. The stimulus that generated the Figure 2 EPs involved no change of mean luminance: the transition from blank field to pattern and back again was accomplished with no change in total light flux. Figure 3 shows a recording in which increase of contrast was accompanied by a small increase of local luminance, and a recording in which the same increase of contrast was accompanied by a small decrease of local luminance.

Figure 3 demonstrates that the main component of EPs to contrast increase is indeed mainly responses to contrast change, and is not an artifact of local luminance responses. (This conclusion does not necessarily hold for all components, nor for all check sizes, nor for all
Figure 3. These evoked potentials were recorded while the subject viewed a pattern of checks that appeared (APP) and disappeared (DIS). $X$ and $Y$ signify alternate checks as marked in Figure 1.

In the uppermost panel, checks appeared and disappeared with no change in mean luminance, since when $X$ checks increased intensity $Y$ checks decreased by exactly the same amount and vice versa. In the middle panel $X$ checks only changed intensity while $Y$ checks remained at constant intensity (Figure 1A). In the lowermost panel $Y$ checks only changed intensity while $X$ checks remained at constant intensity (Figure 1B). The traces show that the main appearance component was chiefly due to contrast change and not to local luminance change. Checks were 80 min arc and electrode positions. The test must be repeated for each new stimulus condition.) To the best of my knowledge, Figure 3 is the first time that this stimulus manipulation has been carried out for an electronically-generated stimulus. Figure 3 shows that our electronically-generated display enables verification that an EP is a genuine contrast response, and this verification can be carried out under computer control in the course of routinely measuring visual acuity or contrast sensitivity.

Now we turn to the sinewave grating stimulator. This stimulator has the following facilities: (1) Successive presentation of four predetermined

$A + B$ was 80% contrast. Stimulus rate 1.2 Hz, sweep time 800 msec, 50 sweeps, two repeats. Positive upwards.
contrast levels can be interleaved so that four EPs are recorded simultaneously. This interleaving procedure combats the disturbing effect of slow EP changes with time so as to improve the accuracy of measuring EPs for different contrast levels. The interleaving procedure is carried out by specially-constructed electronics controlled by a Commodore PET microcomputer. Averaging is achieved by means of a hard-wired four-channel averaging computer (Nicolet CA-1000). Grating stimuli are displayed on a CRT made by Joyce; (2) The direction of contrast change and local luminance change can be dissociated (as described for the checkerboard stimulator) so as to verify that the sinewave grating EPs are genuine responses to contrast and are not artifacts of responses to changes in local luminance.

Figure 4 shows EPs to the appearance and disappearance of a sinewave grating pattern of spatial frequency 2.5 cycles per degree. Reading from the top, the four traces are responses to gratings of contrasts 12.5%, 25%, 50% and 100% respectively. There are 50 sweeps for each trace, and the four stimuli were randomly interleaved in blocks of four. The stimulus cycle time was 600 msec and sweep time 500 msec. Figure 4 shows how the amplitude of the C2 component of the appearance EP rapidly increases with contrast only up to a contrast of 25-50%, and then saturates at higher contrasts. The disappearance EP, on the other hand, is only evident at the highest contrasts.
Figure 4. Averaged transient evoked potentials elicited by the appearance and disappearance of a sinewave grating pattern of spatial frequency 2.5 cycles per degree. Reading downwards from the top, contrasts were 12.5%, 25%, 50% and 100%. Fifty presentations of each contrast were recorded, interleaving in blocks of four. Stimulus cycle time 600 sec, sweep time 500 msec. Positive upwards.

Conclusions

Visual evoked potentials can be used to objectively assess visual acuity and visual contrast sensitivity. (6,7) Human visual responses to pattern and to local changes of luminance can be disentangled. Electronically-controlled visual stimulators allow rapid computer-controlled recording methods to be used.

We have shown that electronically-controlled visual displays can be constructed that are adequate in the following respects:

(a) Stimulus edges are sharp even for 10 min arc checks in a 5° field, and contrast changes are sufficiently free from luminance artifacts so that the EPs to pattern appearance and disappearance are similar to those obtained with the best optical stimulators.
(b) Switching between pattern and blank fields is sufficiently well-balanced that artifact-free contrast EPs can be recorded down to near-threshold contrast levels.

(c) The direction of contrast change and the direction of local luminance change can be dissociated, both for checkerboard and for sine-wave grating stimuli, so that verification of contrast responses can be carried out (see Figures 1 & 3).

(d) It can be arranged that both stimulus contrast and spatial frequency are under computer control, as is the memory location in the averaging computer, so that the presentations of different stimuli can be randomly interleaved by the use of appropriate software. When combined with signal averaging, this procedure improves accuracy since it minimizes the disturbing effects of EP nonstationarity.

References


APPENDIX 1

Pattern stimulation does not necessarily give pattern EPs

Presenting a patterned stimulus to the eye does not necessarily give an EP that is entirely (or even partly) specific to pattern, even when there is no change in total stimulus light flux.* For example, in pattern-reversal stimulation the bright and dim checks abruptly exchange places so that there is no change in total light flux. How, then, can there be any luminance stimulation? Indeed, if the receptive-field size for the luminance mechanism is very much larger than the check size, then there will be no luminance stimulation because each receptive field will "see" zero change in total light flux. However, if the receptive field for the luminance mechanism is about the same size as a check (or smaller) and there is some nonlinear distortion before spatial summation, then there can be a luminance response. Imagine that one receptive field is stimulated by repetitive changes of intensity at a frequency $F$ Hz. Imagine that the neighbouring receptive field is similarly stimulated but in the opposite phase, so that the first receptive field is brightest when its neighbour is darkest. (Thus, the two receptive fields are on opposite sides of the contrast border whose contrast reverses at a frequency of $2F$ Hz.) The point of all this is as follows: it is known that, due to a rectifier-like nonlinearity, local luminance changes at $F$ Hz will generate distorted signals containing a component at $2F$ Hz, so that after spatial summation (whose effect is to cancel the $F$ Hz signals) there will be a residual $2F$ Hz

* Flashed-pattern stimulation may, of course, produce responses to luminance change as well as to pattern. In addition there may be EP components related to nonlinear interactions between luminance and pattern responses, but we do not discuss this form of stimulation here.
signal due to local luminance flicker; this residual signal has exactly
the same frequency as genuine responses to contrast reversals. The
important point is that this net response could occur in the absence of
any pattern response (where a true pattern response is generated by a
change in spatial contrast across a contrast border).

In general, an EP to pattern stimulation contains both a pattern-
specific contribution and a local luminance contribution. Note that the
two contributions have identical temporal repetition frequencies. As
check size rises (or spatial frequency falls), the local-luminance contrib-
ution will grow relatively larger. A procedure for disentangling the
two contributions has been described for pattern appearance/disappearance
EPs. (8) (Note that blurring does not distinguish them). For pattern
reversal EPs Badis Wollner and Hendley(9) have discussed a way of distin-
guishing the two contributions.

The Wollner group's test is illustrated in Figure 1. The essential
point is that in A, contrast decreases when total light flux decreases,
whereas in B, contrast increases when total light flux decreases. Thus,
changes of light flux are dissociated from contrast changes. The upper
panel shows a check pattern with alternate checks marked "A" and "Y".
The intensities of the X checks are modulated as shown in A (continuous
line), and the averager is triggered by the modulating waveform. The
other checks (Y) are held at a constant intensity, carefully preset to
the level illustrated (dashed line). The EP in A is clearly asymmetric,
but note that it is not possible to say that the right-hand section is
characteristic of "pattern appearance" rather than "light flux increase".
In B the stimulating squares (X) are the same as in A, but the constant
intensity of the Y squares has been preset to a different level. One possible outcome is illustrated by the EP waveform b. Here the EP asymmetry has reversed, showing that the first part of the waveform is a response to pattern appearance rather than to light flux increase. A second possible outcome is illustrated by the EP waveform a. The EP asymmetry has not been reversed by the stimulus manipulation. Thus, the second part of the waveform a is a response to light flux increase, and this test has given no evidence for a true response to contrast change. A third possible outcome is intermediate between the waveforms a and b. This would mean that the waveform contained responses to both contrast change and light flux change. By way of illustration, one application of this test has been to show that electroretinograms (ERGs) elicited by pattern stimulation are most probably responses to local changes of luminance rather than genuine contrast responses. Clearly, this test cannot be used when the EP is symmetric, as in the case of responses to pattern reversal.

References


<table>
<thead>
<tr>
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\[ a \Rightarrow b \]

\[ \text{Function Table} \]

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\[ \text{Diagram} \]
Pin Connections for R522 Connector.

1. 113a
2. 113b
3. 113c
4. 113d
5. 113e
6. 113f
7. 113g
8. 113h
9. 113i
10. 113j
11. 113k
12. 113l
13. 113m
14. 113n
15. 113o
16. 113p
17. 113q
18. 113r
19. 113s
20. 113t
21. 113u
22. 113v
23. 113w
24. 113x
25. 113y

1. 0 (IIC)
2. 1
3. 2
4. 3
5. 4
6. 5
7. 6 (MOB)
8. A
9. B
10. A
11. B
12. C

Set Multiplexer Frequency

Select Stimulus Condition A

Select H of Checks / Frame

CLR

Trigger Check A (1)

Trigger Check B (1)

Trigger Check A or Check B (11) 150.5

Frame Reset Pulse (17) 150.5

Select H of Checks / Frame
2450 REM
2460 REM LDA #80           ! INITIALIZE INPUT
2465 REM STA INTRUF
2470 REM JSR HAITCA
2475 REM LDA CON
2480 REM ORA #38
2485 REM STA INTERRUPT
2490 REM JSR HAITCA
2495 REM LDA #80           ! INITIALIZE OUTPUT
2500 REM STA TIME
2505 REM LOOP3            ! WAIT END OF PRESENTATION
2510 REM JSR HAITCA
2515 REM LDA USRPT
2520 REM AND #55
2525 REM ORA HAITIF
2530 REM STA HAITIF
2535 REM LDA TIME
2540 REM JMP USRPT
2545 REM ONE LOOP5
2550 REM JSR HAITCA
2555 REM LDA CON
2560 REM STA INTERRUPT
2565 REM LOOP4            ! WAIT END OF PRESENTATION
2570 REM JSR HAITCA
2575 REM LDA USRPT
2580 REM AND #55
2585 REM ORA HAITIF
2590 REM STA HAITIF
2595 REM LDA TIME
2600 REM JMP USRPT
2605 REM ONE LOOP6
2610 REM LDA #0
2615 REM STA JHVCBLK     ! CLEAR JH VCLOCK
2620 REM JSR HAITCA
2625 REM LDA USRPT
2630 REM AND #55
2635 REM ORA HAITIF
2640 REM ONE LOOP6
2645 REM CLI              ! CLEAR INTERRUPT
2650 REM RTS             ! EXIT TO BASIC
2655 REM HALT HAITCA LDA CURST
2660 REM LOOP LDA CMAINP
2665 REM RND #2
2670 REM BEQ LOOP
2675 REM LDA TIME         ! INTERRUPT TIME
2680 REM CLC
2685 REM ADC #1
2690 REM STA TIME
2695 REM RTS
2700 REM HAIT Run assembled
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READY.
EXECUTION INSTRUCTIONS

INITIAL STEPS

- Switch on P1
- Check to see if it is in recorder
- Type 1000 then hit 'Return'
- Press 'Play'

While P1 is booting:
- Switch on Tape (check it is set to 100 format etc)
- Switch on Headset
- Switch on Mic/lot

Before the computer:
- Type 25 then hit 'Return'
  - If not 0 then there has been a load error, switch off P1 and try again. If two load errors, contact K1B
- Type 4444 then hit 'Return'
  - The program starts
- Switch on Electroenceph box
- Follow instructions of the program CAREFULLY

Note:
- Hit 'Return' after every entry

Data entries have a default value if it appears beside the flashing cursor. Simply hitting 'Return' will enter this value. To alter the value type the new value over the old and hit 'Return'

If each question has only a limited range of acceptable answers, these are printed. This is given in brackets after the question. If you read a value outside this range you will have to contact K1B (and it probably will not be possible, anyway).

1) If you want the grating to be presented with approximately equal on-off intervals, then:
   - The grating presentation time must = Niclot + on time + 125 ms.
2) If it is not possible to have GPT < 50ms or GPT > NST - 100ms

Contrast Rate CALIBRATION:

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</tr>
<tr>
<td>3</td>
<td>50%</td>
</tr>
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<td>4</td>
<td>100%</td>
</tr>
<tr>
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<td>6.25%</td>
</tr>
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(d)

D. Regan

PUBLICATIONS

(not including abstracts)

Books


Papers


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120. Regan, D. & Beverley, K.I. How we avoid confounding the direction we are looking with the direction we are moving. Science, submitted.
(e) LIST OF PROFESSIONAL PERSONNEL ASSOCIATED WITH THE RESEARCH EFFORT

D. Regan, D.Sc. (Higher doctorate in Science & Medicine, London, 1974);
Ph.D. (Physics, Imperial College, London, 1964); M.Sc., DIC (Physics,
Technical optics, Imperial College, London, 1958); ARCS, B.Sc. (Physics,

(f) INTERACTIONS

Invited participant in Workshop on visual aspects of flight simulation,
NASA/NATO, Ames Research Center, California (1980).

Invited speaker at Workshop on Visual Cues in Flight Simulation, NRC
Committee on Vision, Phoenix, Arizona (1980).

Invited speaker at Atlantic Provinces Ophthalmologists Society annual
meeting, Halifax, Canada (1980).

Invited lecture at Workshop on Physiological Basis of Evoked Potentials,
Sloane Foundation, Carmel, California (1980).

Invited lecture on physiology of motion and depth vision, Satellite Symposium
of International Physiological Congress, Braunlage, West Germany (1980).

Invited lecture on the physiology of binocular vision, annual meeting of
the International Society for Clinical ERG, Amsterdam (1980).

Invited lecture on motion perception and skilled tasks. Concordia
University, Montreal (1980).

Visiting Professor series, invited lecture to Ophthalmology Department,
Tufts University, Boston (1981).

Two invited lectures on visual diagnostic methods at Neuro-ophthalmology
Course, Bascom Palmer Eye Institute, Miami (1981).

Invited lecture on visual and auditory tests in multiple sclerosis at a
Workshop on Basic and Clinical Electrophysiology of Demyelinating Disease,

Invited lecture at Evoked Potentials Conference, McMaster University,

Invited lecture on motion in depth. Neurosciences Program, University


(g) PATENTS

No patents arising from this grant.