Cortical Potentials Associated with the Detection of Visual Events

Abstract. *A positive-going potential, which reaches a maximum at the vertex and midline parietal scalp electrodes, occurs in the human being when an infrequent, significant event occurs in a continuously observed visual display. It is not time locked to eye movements or operant response and appears to be generated when the observer recognizes an event that he has been instructed to detect.*

The early works of Caton (*1*) and Berger (*2*) included reports on changes of brain electrical activity associated with visual input. More recently Gastaut (*3*), Evans (*4*), and others have shown that specific electroencephalographic (EEG) activity (lambda waves) can occur when the subject scans a picture. In a few people the lambda activity is relatively large (30 μv) and can easily be seen in recordings from scalp electrodes. Recent developments of signal averaging techniques now allow the measurement of much smaller potentials in the presence of larger background EEG. Such procedures have been used to identify the brain responses associated with saccadic eye movements (*5*), and the ease of this technique encourages the study of information processing in the visual and other sensory systems (*6, 7*). However, averaging requires repetition of the stimulus event, and this sometimes imposes an artificiality on experimental situations. We shall show that in certain conditions the detection of changes in a visual display is accompanied by recognizable cortical potentials that often are large enough to dispense with the repetitive techniques.

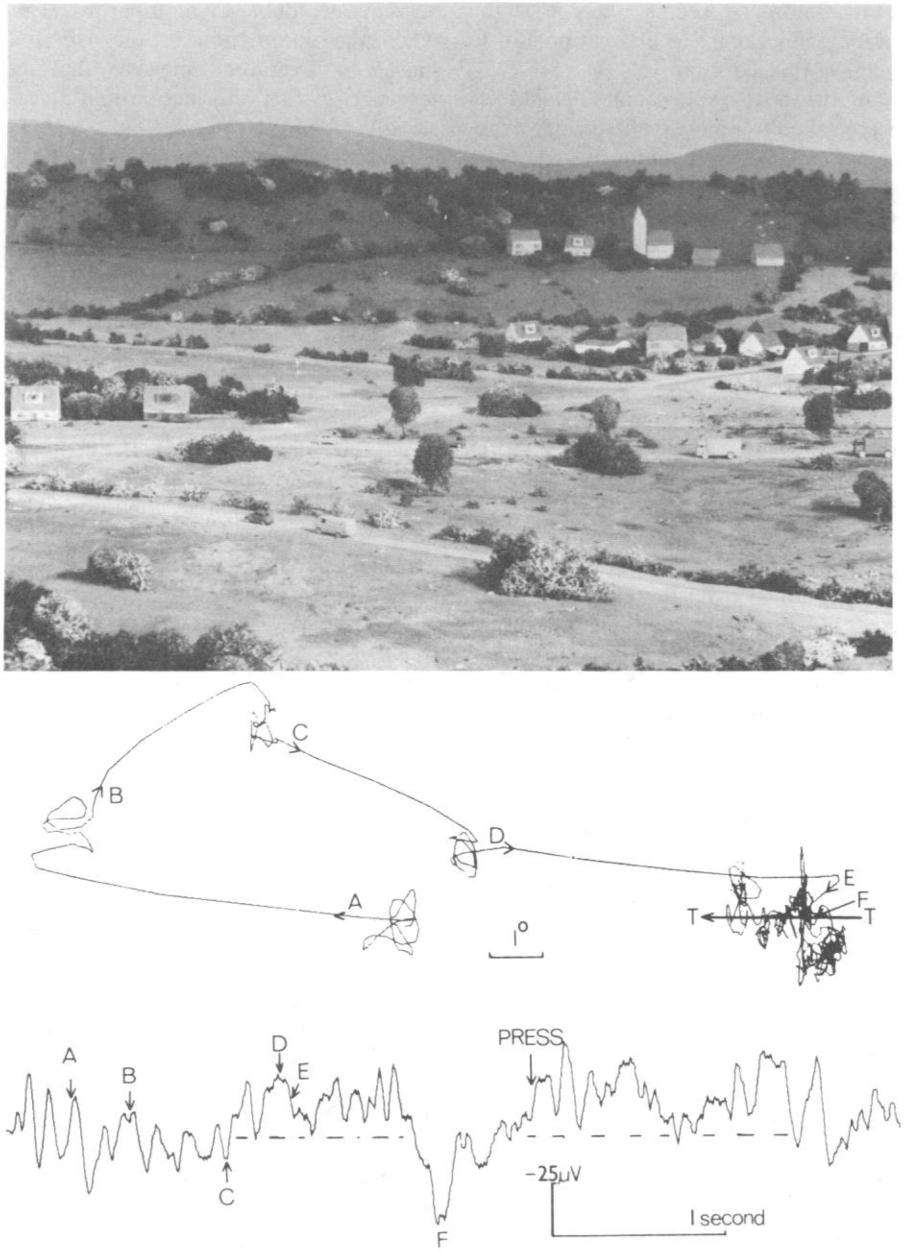


Fig. 1. (Top) The visual display and (bottom) the eye-scan pattern, track of vehicle (*T*), and vertex EEG before and after detection of vehicle. The vehicle traveled from right to left across the middle of the display. At the start of this section of the record the eyes were looking at the center of the display. At *A* the eyes moved to the left side and scanned there until *B* when saccades to the upper center (*C*) and right (*DE*) occurred followed by detailed movements leading to the detection potential at *F* and tracking thereafter. All six vehicles are shown in the visual display.

To study the vigilance of operators watching a visual display for a long time a video tape recording was made by televising a model landscape across which correctly scaled vehicles—cars, vans, and trucks—moved singly at infrequent, unpredictable times. The observer, seated in a darkened room 2 m from a 25-inch (63.5-cm) television monitor (the angle subtended by the landscape at the observer was 16° in the horizontal plane), was instructed to press a switch with his left thumb whenever a vehicle appeared in the display and to press another switch with his left index finger when the vehicle was recognized as a car, van, or truck, using a code for each type of vehicle. The maximum angle subtended at the eye (by a truck in the foreground) was 0.5°, the minimum (by a car in the background) was 0.25°. The mean contrast of the vehicles against the background was set at 20 percent, although the value changed considerably as the vehicles crossed the landscape (*8*). The brightness of the whole display was set for comfortable viewing in a darkened room. Vehicles entered along any of four roads from the left or right or from behind clumps of trees in the middle of the picture. The order in which the vehicles were presented and the routes along which they moved were randomized. The average time interval between events was 4 minutes; a total of 24 events occurred in the 1½-hour watch period. The time taken for the vehicle to cross the display varied according to the route and ranged from 8 to 30 seconds. The speed of the vehicles was controlled by an electric motor and was equivalent to 10 miles (16 km) per hour.

Recordings were taken from scalp electrodes Fp_z (mid frontal), C_z (vertex), and O_z (mid occipital) referred to linked electrodes on the mastoid processes (2M) and from bipolar montages O_1 to P_3

and O_2 to P_4 (9) in six normal volunteer subjects. Vertical and horizontal eye movements were recorded by means of electrodes placed above and below the right eye and on the outer canthi, respectively. These electrooculograms and EEG's were recorded by means of d-c amplifiers or amplifiers having an 8-second time constant (10). The vertex channel was usually compensated for eye movements according to the method described by McCallum and Walter (11). Respiration, electrocardiogram (EKG), heart rate, galvanic skin response (GSR), and the myogram (EMG) of the neck and eyes and operant muscles on the left arm were recorded. The upper frequency response of the amplifier was 70 hertz (−3 db). Switch presses were also indicated on the record. In a further three subjects the spatial distribution of the cortical potentials was determined by using electrodes Fp_z, F_z, C_3, C_z, C_4, P_3, P_z, P_4, O_1, O_z, O_2, and an electrode 3 cm posterior to O_z each referred to 2M.

The 16 data channels were each sampled at 100 points per second by a PDP 12 computer and stored on digital magnetic tape. The sampling started shortly before the vehicle entered the display and ended 16 seconds later. The data were analyzed with the PDP 12.

Nearly all events were detected by all observers although the time taken to do so varied greatly across vehicles, routes, and observers. The mean detection time, that is the time taken between the entry of the vehicle into the display and the press of the switch to indicate detection, was 4.3 seconds with a range of 0.4 to 25 seconds. This meant that most vehicles were well into the display before the response was made. A further 2.4 ± 2 seconds was required before the observers indicated that they had recognized the vehicle as a car, van, or truck. A two-dimensional display of the horizontal and vertical eye movements showed that on most occasions the eyes were scanning various parts of the landscape during the time between the entry of the vehicle and detection (12). About 1 second before the switch was pressed to indicate detection, the gaze transferred to the region of the vehicle and detailed scanning of this part of the display began. During this scanning a large, discrete, well-defined, positive-going potential occurred in the EEG (Fig. 1).

The potentials recorded from the six midline electrodes during the same event as in Fig. 1 are shown in Fig. 2. These recordings show the maximum positivity occurring equally at the vertex (C_z) and midline parietal (P_z) electrodes with smaller amplitudes at frontal (F_z) and occipital (O_z) electrodes. There are no obvious positive potentials at the appropriate time at the frontal pole (Fp_z) or the deep posterior ($O_z - 3$ cm) electrodes. In this event the positivity occurred about 0.8 second after the ocular movement (D to E) that took the eyes into the area of the display containing the vehicle. The EMG of the operant arm muscles started to increase immediately after the positivity and culminated in the switch being pressed to indicate detection 0.45 second later. The average amplitude of the detection positivity measured at the vertex for the nine subjects was 38 μv; mean amplitudes for individual subjects ranged from 20 to 63 μv. The average spatial distribution of the amplitude of the positivity for three subjects is shown in Fig. 3.

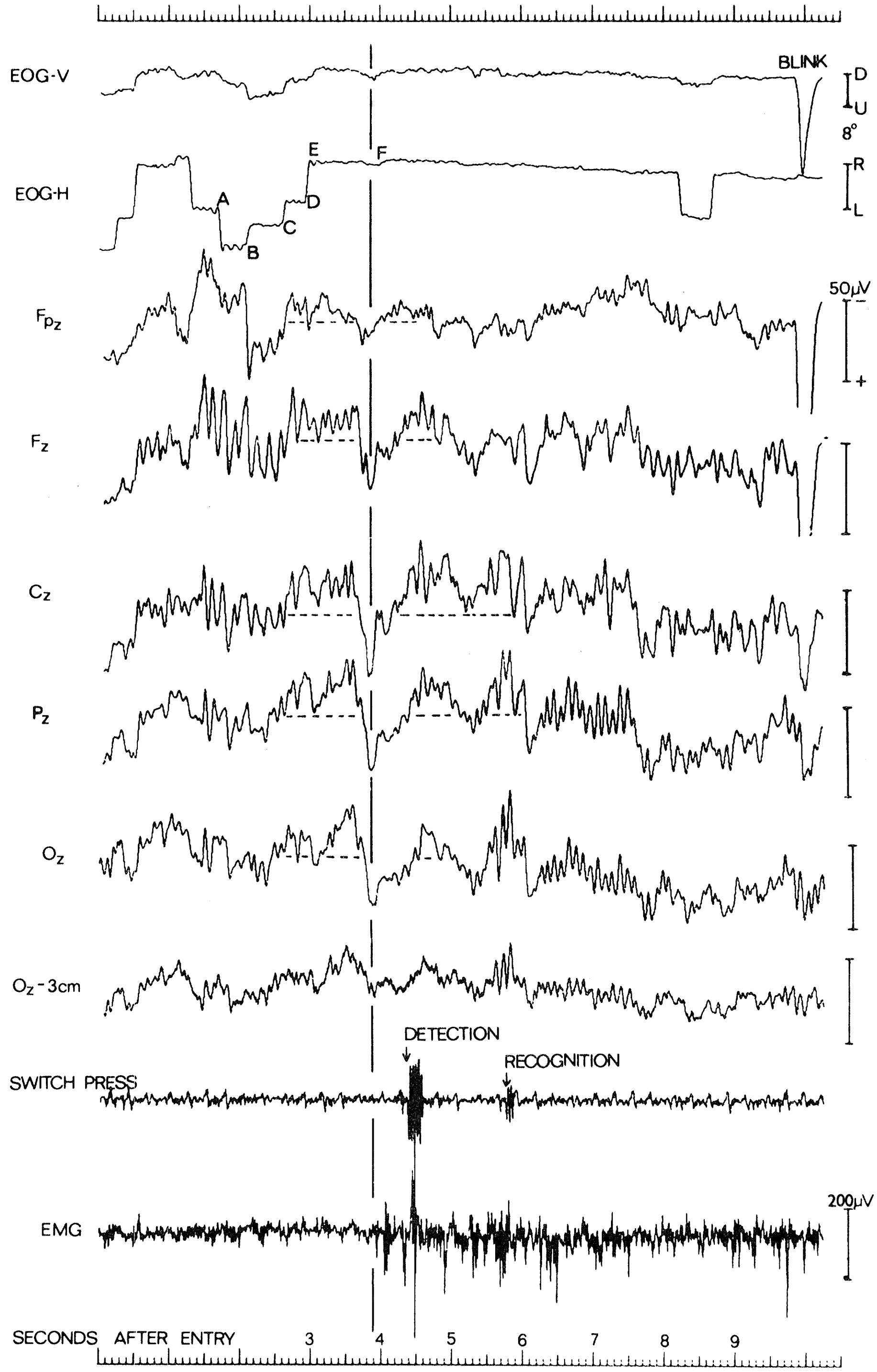


Fig. 2. Record showing detection positivity 3.8 seconds after vehicle enters the display. The switch is pressed 0.45 second later. The second press of the switch indicates recognition. Before detection the eyes were scanning from side to side of the display but there were no obvious cortical potentials in the EEG associated with these eye movements. The EMG of the operant muscle leading to the first press started increasing shortly after the positivity. Oculograms were recorded with d-c amplifiers.

The waveform in the occipital region was usually more prolonged than in the frontal region. When averaged across events the time of occurrence at the vertex and occipital electrodes was the same (within ± 10 msec) in seven subjects; in two subjects the occipital preceded the vertex potential by 20 and 35 msec.

The average amplitude of the positive potentials showed a small reduction in the second half of the experiment in most subjects, but this reduction only reached a significant level in one of them (*13*).

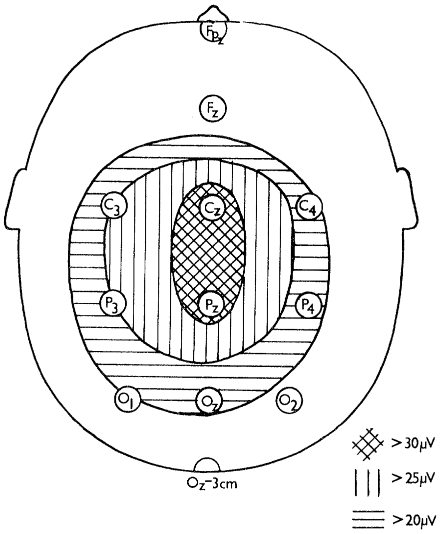
The positive potentials always occurred after the point of gaze had moved into the region of the display that contained the moving vehicle. However, the potentials were not directly related in time to the eye movements; the delay ranged from 0.1 to 2.0 seconds after the last large eye movement that took the eyes into the appropriate part of the display. When the EEG data were averaged with the eye movement being used as the reference point, the potential was very small (less than 10 μv) and was similar to the potential related to random eye movements. These eye movement related potentials were much smaller and of different waveform from the detection positivity. Tracking of the vehicle by the eyes started at about the time when the detection positivity occurred.

The press of the switch to indicate detection occurred after the potential, but this too was not time locked to it, varying from 0.1 to 2.5 seconds. Details of the time relationships between the detection positivity, the eye movement, and the switch press are shown in Fig. 4 together with the averaged vertex EEG for each of six subjects. The finger press indicating recognition (car, van, or truck) occurred after the thumb press for detection but the time interval between them varied considerably. There were no large discrete potentials similar to the detection positivity before this finger press even when there was an interval of several seconds indicating that the observer was having difficulty in deciding upon the type of vehicle.

An additional two subjects were asked to press the switch only when they saw a car and not to press when they saw a truck or van. Positive potentials of similar amplitudes were recorded to all events, not just the ones to which motor action had to be taken.

A feature of many recordings was a slow increase of negativity that started before the detection positivity. This can be seen in Figs. 1 and 2. The onset of this negativity is not easy to determine because of its relatively low final value (usually less than 20 μv), its slow rate of change, and because of the spread of eye movement artifacts. As shown in Fig. 1, the negativity can start to increase while the eyes are scanning other parts of the display, and it decreases after the completion of the motor tasks indicating detection and recognition.

The determination of whether significant events in a visual display have been detected depends on a number of peripheral and cerebral processes leading to appropriate motor action that indicates to the external world that the event has been seen. In our recordings of the electrical activity of the brain, the first sign of these processes is the slow rise of negativity at the vertex and parietal electrodes even when the eyes are scanning other parts of the display. Because of the lack of a time fiducial mark that would



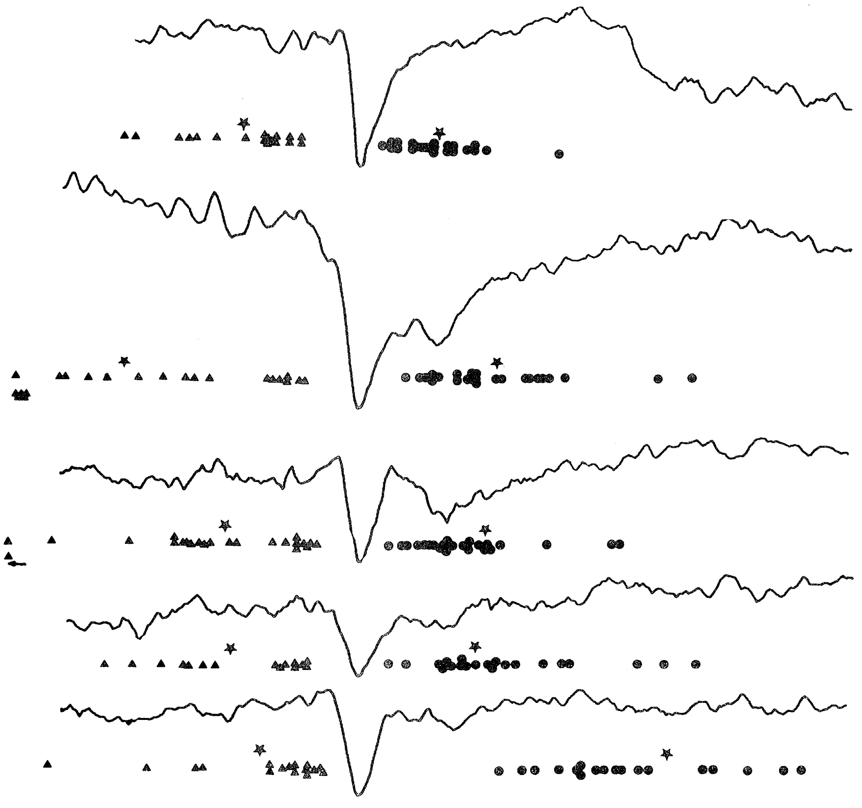


Fig. 3 (above). Mean spatial distribution of detection positivity for three subjects. The mean values at the vertex and parietal electrodes, respectively, for each subject were 21, 25 μv; 31, 33 μv; and 41, 34 μv. Fig. 4 (right). Average vertex detection potentials for each subject and their time relationship with the end of the last large eye movement before tracking (triangles to left of zero time) and switch press (dots to right of zero time). Averages of these times are shown by stars. Because there was no time instant to which the EEG could be synchronized the averages were obtained by using the largest potential occurring at the vertex in the interval between the last large saccade before tracking started and the press of the switch. The scatter of the occurrence of eye movements and the switch press demonstrates the absence of a fixed time relationship with the detection positivity.

permit the use of signal enhancement techniques, this change is difficult to isolate but presumably starts when something seen in peripheral vision directs the eye scan toward the area of display containing the vehicle. It is similar in form to the contingent negative variation (*14*) and may indicate preparation for action.

However the main cortical sign of detection is the occurrence of a large positive potential maximum at the vertex and parietal electrodes shortly after the eyes have fixated in the region of the vehicle. This potential is not time locked to the large eye movement that brings the point of gaze into the region of the vehicle, although such potentials may be related to fine eye movements below the resolution of the oculogram. They occur when the observer has seen the vehicle and started to track it and could represent the changeover from the scanning to the tracking mode of the eye (*15*). However, as shown in Fig. 1, at 8 seconds after entry the reacquisition of the vehicle and the resumption of tracking after the eyes have flicked away for 500 msec is not accompanied by an obvious positivity. Nor are these potentials dependent on the execution of a motor action since they also occur when the observer sees a vehicle to which he must not respond by pressing the swtich. In this situation, however, it is still necessary for the observer to detect the vehicle in order to decide not to press. Thus it appears that the positivity occurs when the observer sees one of a class of events that he has been told to detect.

Both the role of these potentials, their distribution, and their positive polarity suggest that they might have common origins with the P300 component of the cortical evoked potential which occurs characteristically during discriminating and decision-making tasks (*16*). The amplitude of this component is usually less than 10 μv although Courchesne *et al.* (*7*) show a P300 component of 30 μv to the first presentation of the stimulus and Vaughan and Ritter (*17*) describe large potentials to infrequent events.

What the latency of 300 msec would mean in our experiments is difficult to tell because the vehicle is there for several seconds before it is seen; but often the occurrence of the P300 in other experiments is not accurately time locked to preceding events (*18, 19*). It may be related to the last microeye movement that finally confirms the existence of the vehicle, since the distribution of eye movements preceding the positivity (Fig. 4) is not normal and has a group of values of about 200 msec in most subjects. The hypotheses that have been advanced to describe the psychological nature of the P300 wave, such as the resolution of uncertainty (*20*), the orienting response to an unexpected stimulus (*21*), the stimulus-independent perceptual decision process (*19*), or the matching of a neural template (*22*) might have some relevance to the origin of the detection positivity and could lead to new experimentation that could advance our knowledge of what we mean by "seeing" a target.

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8. Contrast here is defined as $[(W - B)/(W + B)] \times 100$ where W and B are the brightness of the white and black parts of the display.
9. These electrode designations are part of the standardized placements known as the 10–20 system.
10. Amplifiers having an 8-second time constant were used to stabilize drift due to electrodes. This bandwidth is sufficient for determination of scanning pattern and the beginning of tracking. In three subjects, d-c amplification and very stable electrodes were used for scanning and for tracking the vehicle.
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12. By means of high-quality silver–silver chloride electrodes, the oculogram can be used to locate the point of gaze to about ± ½° for short periods of time (30 seconds). In our experiments long-term instability is corrected by positioning the two-dimensional display from the known position of the eyes and vehicle during tracking.
13. In subject S2, the average amplitude at the vertex decreased from 71 ± 10 μv to 55 ± 8 μv, $P < .002$.
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Reading Disability: An Information-Processing Analysis

Abstract. *In a task designed to separate perceptual processes from memory, 12-year-old children with reading disabilities showed no perceptual deficits as compared to their peers. However, they exhibited major deficiencies in memory skills for both labelable and nonlabelable visual information. Reading-disabled children in this age group appear to suffer from a basic information-processing deficiency.*

The nature of reading disability has been one of the most difficult and puzzling problems facing psychologists and educators. For years reading problems were thought to be a difficulty in the perception of written symbols. As recently as 1972 Cruickshank concluded that reading disabilities ". . . are essentially and almost always the result of perceptual problems based on the neurological system" (*1*). However, recent work has cast doubt on this "perceptual deficit" hypothesis and pointed instead to deficits in memory processes (*2*). One persistent problem in assessing reading disability has been the inability to devise experimental procedures for separating perception from memory (*3*). Recently techniques have been developed for isolating perceptual and memory processes by assuming them to be occurring sequentially in time (*4*). It has been demonstrated experimentally that initially large amounts of information are perceived by the visual system. This information persists in a raw perceptual form (called visual information storage or VIS) for about 0.25 second. During this period subjects are actively coding and transferring information into a more permanent storage (called short-term storage). The ability to temporally separate perception