ing period after announcement of the test, and actual performance; a different picture is found with bilaterally symmetric lead configurations, in which the waiting period is similar to the idle EEG (*12*).

The use of 100 consecutive trials in each of the three behavioral situations provides substantial assurance against errors arising from inadequate population size. As concerns inherent statistical errors, the type I error ("false negatives") is fixed in all three situations, since it is solely determined by the significance level chosen; the type II error ["false positives" (*14*)] is likely to decrease as the percentage of failures goes up (*12*). Hence any possible error in Table 1 may only be in direction of underestimating the decline in Gaussian behavior induced by task performance.

Thus, amplitude analysis of the EEG may provide significant information on mental function. These results have since been confirmed with additional subjects, and with greater number of scalp leads (*12*). It has often been assumed that low-voltage, fast activity implies "desynchronized EEG," and high-voltage, slow activity is indicative of "synchronization." There may be some justification for this usage from a descriptive viewpoint, but microelectrode investigations apparently do not support the identification of "synchronized" and "desynchronized" EEG with corresponding changes on the neuronal level. Therefore, a particularly important feature of our amplitude analysis is the straightforward interpretation which may be made in terms of unitary neuronal synchronization and desynchronization. Although this interpretation still lacks direct experimental proof, it is difficult to conceive of any process apart from a change in relation of individual generators, which could bring about such marked increase in rejections in the χ^2 test (*11*). As with many other statistical tests, however, the results only apply to the population as a whole, and any mechanism which acts on the neuronal population (such as subcortical "pacemakers") is bound to affect the statistical interrelations of the neural elements contributing to the recorded surface EEG.

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6. In summation of synchronized generators, Gaussian activity would also ensue, provided that the probability functions of these generators would be identically normal. This cannot however be the case with the neuronal wave generators, as the probability distribution of those is non-Gaussian (see *3*).
7. This statement follows directly from the central limit theorem of statistics: the sum of a large number of independent variables (or generators) is distributed normally, regardless of the probability distribution of the individual variables, and provided only that they possess finite mean and variance.
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Attention Reduction and Suppressed Direct-Current Potentials in the Human Brain

Abstract. *Distraction suppresses direct-current potentials (contingent negative variation) recorded from the human scalp. This reduction is accompanied by retarded reaction time. Contingent negative variation and reaction time appear to reflect a common process, attention.*

Electrophysiological studies of normal mental processes are relatively incomplete. With the advent of computers, study of electrical brain activity and information processing has increased (*1*). Computer averaging techniques have been widely used in studies of averaged evoked potentials and attentional processes (*2*). Using such techniques, Walter discovered a reliable d-c potential in the human brain (*3*). This latter phenomenon, contingent negative variation, is an electronegative change in the frontal areas of the human brain which hinges on the association of two successively presented stimuli. A typical experimental situation generating contingent negative variation is that of reaction time. The first stimulus is a preparatory or warning stimulus; the second stimulus is one to which a motor response is required. For example, a light flash (first stimulus) followed in 1.5 seconds by a tone (second stimulus), which is terminated by a key press, gives rise within the interval between presentation of light and tone to a slowly ascending electronegative potential whose maximum of 20 to 30 μv occurs between 0.2 and 1.5 seconds and whose duration is normally terminated with the requisite motor response (Fig. 1). This wave is usually recorded with a scalp lead at the vertex (C_z), the mastoid being used for the reference electrode.

Early studies of contingent negative variation stressed its relation to "cortical priming" with particular emphasis on expectancy, defined as the relative subjective certainty that the first and second stimuli will occur (contingent negative variation was renamed the expectancy wave by Walter) (*4*) and on motivation level (*5*) and conation, or intention to act (*6*). Recently, however, Tecce (*2*) suggested that amplitude of contingent negative variation is primarily related to attention; but no systematic attempt has yet been made to show that attentional processes determine amplitude of contingent negative variation. Our experiment was designed to establish the relation of contingent negative variation and attention by demonstrating that distraction reduces amplitude of contingent negative variation. If the amplitude is

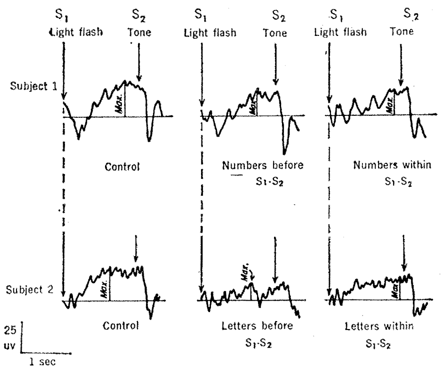

Fig. 1. Suppressing effects of distraction on contingent negative variation amplitude for two subjects. Each contingent negative variation wave is based on six trials. Relative negativity at the vertex is upward. The right mastoid was the reference placement; S_1, first stimulus; S_2, second stimulus.

related to attention to the second stimulus, then requiring attention to events extrinsic to the second stimulus (distraction from it) should result in suppression of amplitude.

The subject was seated in a reclining position in a darkened room. Preparatory stimuli were brief flashes of dim light presented at a lamp 0.8 m from the subject's eyes (*7*). The focal stimulus (second stimulus), to which fast responses were required, was a continuous 2500-hz tone presented through a speaker 0.7 m from the subject's right ear (*8*). The tone was terminated by the subject's telegraph key press (*9*). The reaction time was measured to the nearest 5 msec.

There were five control and four distraction conditions. A control trial consisted of the light flash (first stimulus) followed in 1.5 seconds by tone (second stimulus) and the subject's motor response. There were seven trials in each control and distraction condi-

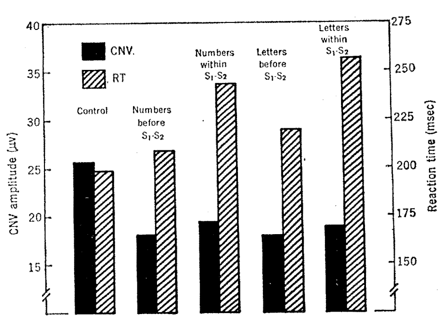

Fig. 2. Decrease in mean contingent negative variation (*CNV*) amplitude and increase in mean reaction time (*RT*) for distraction and control conditions. Each value is based on the same 12 subjects; S_1, first stimulus; S_2, second stimulus.

tion. The interval between trials was 26 seconds, and the seven trials lasted 3 minutes. The first trial was excluded from analysis. The four distraction conditions were identical with control conditions except that an additional task was required. Subjects attended to four numbers or four letters spoken by the experimenter either before or within the interval between light and tone, and repeated them aloud after responding to tone. The four distracting stimuli were presented continuously at the rate of one stimulus every 0.3 second. For example, in one distraction task (numbers before first and second stimuli), four numbers were given at variable times (5 to 15 seconds) before the light-tone stimulus complex and were repeated by the subject after his response to tone. Distracting number stimuli ranged from one to nine with no duplication of numbers within a trial and minimum duplication of numbers between trials (for example, trial 1: 2-5-7-4; trial 2: 8-6-3-9). In the second task (numbers within first and second stimuli), numbers were administered within the light-tone interval. In the third and fourth tasks (letters before first and second stimuli and letters within first and second stimuli), four letters (A-E-I-O) were used instead of numbers (for example, trial 1: A-O-I-E; for trial 2: O-A-E-I). Thus, in the two "letters" tasks, there was high repetition in content of distracting stimuli, whereas in the two "numbers" tasks there was low repetition; consequently there were two extremes in difficulty.

The procedure consisted of a 15-minute rest, 10 to 15 practice trials, and the five control and four distraction conditions, presented within a Latin-square design (*10*, *11*, pp. 539–543). Electrical activity was recorded by nonpolarizing Ag-AgCl electrodes filled with Sanborn Redux (*12*) placed on the vertex(C_z) and right mastoid. Signals were fed into a directly coupled low-level d-c preamplifier (Grass 7 PlA) with a gain of 100 μv/cm and then further amplified and filtered (Grass 7 DAB). Signals were recorded on an FM tape recorder and simultaneously averaged on a computer of average transients (CAT 400A) (*13*). On-line photographs of averaged contingent negative variations ($N = 6$ trials) were taken from the CAT scope with a Tektronix oscilloscope camera (model C-27). For each subject, there were nine averaged contingent negative variations—one for each of the five control, and four distraction conditions.

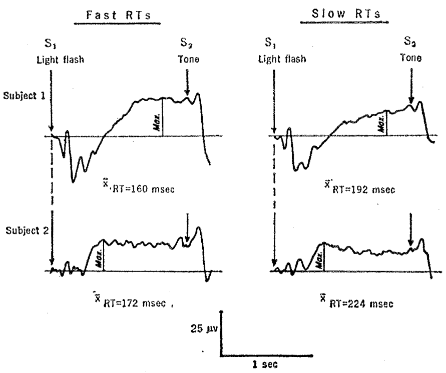

Fig. 3. Averaged contingent negative variations ($N = 24$) for two subjects showing the relation of high contingent negative variation amplitude to fast reaction time (*RT*). Relative negativity at the vertex is upward. The right mastoid was the reference placement.

Amplitude of contingent negative variation was measured from base line to the maximum negative voltage attained in the 1.5-second interval between first and second stimuli for an averaged contingent negative variation (Fig. 1). Recordings of eye movements were made on four subjects; electrocardiograms (EKG's) were recorded from 11 subjects.

We found significant relations between distraction and amplitude of contingent negative variation, distraction and reaction time to tone, and the amplitude of contingent negative variation and reaction time to tone. An analysis of variance of group mean voltages was done for the five control conditions (*11*, p. 302). They did not differ (F, .69; d.f., 4, 44) and were consequently combined for each subject to yield a pooled control mean. All analyses of contingent negative variation are based on five voltages for each individual—the pooled control mean and separate values for the four distraction conditions. Reduction in amplitude of contingent negative variation accompanied each of the four distraction conditions (Figs. 1 and 2). The mean voltage for each of the four distraction conditions (Fig. 2) was significantly less than the mean voltage for the pooled control ($P < .01$), as evaluated by analysis of variance and four Dunnett *t*-tests (*11*, pp. 89–92; *14*). These four differences appear to be independent of eye movement potentials (*15*). The means for the four distraction conditions do not differ from each other, as determined by analysis of variance and Newman-Keuls procedures (*11*, pp. 80–95; *16*).

Compared to the control value (*17*),

mean reaction time to tone was significantly slower ($P < .05$) when numbers or letters were presented within the light-tone interval, as determined by two Dunnett t-tests (Fig. 2). However, there was no difference in mean reaction time between the pooled control and conditions where distracting stimuli occurred before the light-tone interval, as evaluated by a second pair of Dunnett t-tests (*18*).

The amplitude of contingent negative variation was significantly reduced in the four distraction conditions; reaction time was increased significantly when numbers or letters occurred within the first and second stimuli interval. To evaluate directly this suggested inverse relation between amplitude of contingent negative variation and speed of response, we analyzed the control conditions. With the use of a LINC-8 computer, each single contingent negative variation in the controls was classified on the basis of the speed of response accompanying it. For each subject, single contingent negative variations for the faster and slower halves of all control reaction times were grouped to yield two averaged contingent negative variations—one for the faster and one for the slower reaction times. For the 12 subjects tested in the basic experiment and for six other individuals, there were sufficient control data for comparison of fast and slow averaged contingent negative variations, each of the two classifications being based on 20 to 32 single contingent negative variations. Of the 18 subjects, 13 had higher contingent negative variation amplitude for the fast reaction times (Fig. 3) than for the slow reaction times, whereas the others showed the opposite effect. The number of subjects showing the expected relation (that is, higher amplitude for faster reaction times) is greater than would be expected by chance ($P < .05$; one-tail test), as determined with a binomial test (*19*). This finding suggests that contingent negative variation and reaction time are manifestations of a common process. Since the amplitude was reduced and reaction time was lengthened when distracting stimuli were given within the interval between first and second stimuli, this process appears to be attention.

Previous experiments have emphasized expectancy (*4*), motivation (*5*), and conation (*6*) as primarily related to contingent negative variation amplitude. However, since first and second stimuli were never omitted in this study, a reduction in "expectancy" of second stimulus is not a likely explanation of reduction of contingent negative variation during distraction conditions. In addition, since subjects uniformly reported greater effort during distraction tasks (that is, doing two things at once—paying attention to numbers or letters and responding to tone), a decrease in general motivation during distraction conditions was unlikely and does not account for reduction in amplitude of contingent negative variation in these conditions. In addition, for 10 of 11 subjects on whom EKG data were available, the overall mean heart rate for the four distraction conditions was higher than for the five control conditions ($P < .02$; two-tail binomial test). Therefore, the finding that most subjects showed elevated levels of autonomic arousal during distraction conditions further decreases the likelihood that decreased motivation or activation level can account for reduction of contingent negative variation found in distraction conditions. Finally, there was no evidence from subjects' reports that intention to respond to the second stimulus was lowered during distraction. Thus, conation is not a likely explanation of reduced contingent negative variation amplitude during distraction. Therefore, we concluded that amplitude of contingent negative variation is a sensitive measure of attentional processes in humans.

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8. The stimulus tone was generated by a Mallory Sonalert audible warning device (Mallory Co., Indianapolis, Ind.) connected to a 23-volt power supply. The tone was 68 db, as measured at the subject's right ear by a sound level meter, type 1551-C (General Radio Co., Concord, Mass.).
9. A weight of 117 g was required to close the telegraph key; switch contacts were 1 mm apart.
10. Four subgroups of three subjects each received separate sequences of control (C) and distraction conditions (numbers before first and second stimuli—NB; numbers within first and second stimuli—NW; letters before first and second stimuli—LB; letters within first and second stimuli—LW); (i) C-NB-C-NW-C-LB-C-LW-C; (ii) C-LW-C-LB-C-NW-C-NB-C; (iii) C-LB-C-LW-C-NB-C-NW-C; and (iv) C-NW-C-NB-C-LW-C-LB-C.
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13. Technical Measurement Corporation manufactured both the FM tape recorder (model 700) and the CAT 400A. This company is now listed as Technical Instruments, Inc., North Haven, Conn.
14. Dunnett t values for comparisons of control and distraction conditions are 3.93, 3.27, 3.99, and 3.65 (d.f., 5, 44) as ordered from left to right in Fig. 2. All statistical procedures used in this report are "multiple comparison" techniques, which insure against chance findings resulting from more than two statistical tests on the same data. Furthermore, they are two-tailed tests, unless otherwise stated.
15. Recordings of d-c potentials from spontaneous eye movements of four subjects showed that amplitude of contingent negative variation was largely unaccompanied by eye movement potentials in the interval between the light and tone. Furthermore, where occasional eye movement potentials occurred, there was no consistent difference in their amplitude for control and distraction conditions (where differences in amplitude of contingent negative variation were found). Therefore, the contribution of eye movement potentials to differences in amplitudes of contingent negative variation in control and distraction conditions appears to be small, if at all present. In addition, for five subjects averaged contingent negative variations for control conditions were of the same shape and amplitude as those measured at the end of the experiment when subjects retained eye fixation on the lamp (source of first stimulus) during the interval between first and second stimuli. This comparison provides further, indirect evidence that eye movement potentials were not a source of amplitude of contingent negative variation during control conditions. Furthermore, 11 subjects stated that they habitually fixed their eyes on the lamp during the interval between first and second stimuli.
16. Six comparisons are generated by the four distraction conditions, taken two at a time. All F's are less than 1 (d.f., 2 to 4, 44).
17. For the 360 control trials (12 subjects in five control conditions per subject in six trials per control condition), premature responses to tone occurred five times or less than 2 percent of the total number of control trials. Therefore, reaction times are based on true responses to tone and are not due to a time-estimation process, that is, guessing when the tone would occur.
18. Dunnett t values for comparisons of control and "numbers-within" and "letters-within" conditions are 2.65 and 3.42, respectively (d.f., 5, 44). For comparisons of control and "numbers-before" and "letters-before" conditions, the t values are .63 and 1.29, respectively (d.f., 5, 44).
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