Reports

Variations in Alpha Voltage of the Electroencephalogram and Time Perception

Abstract. *Human subjects were instructed to respond regularly at 3-second intervals while their brain waves were recorded and analyzed. When subjects were alert the time between two successive responses did not vary greatly; however, as subjects became increasingly drowsy these times lengthened and the mean voltage of the peak alpha frequency decreased.*

In keeping with the commonly observed fact that monotony tends to induce drowsiness, the specific task of repeatedly tapping a telegraph key every few seconds without prompting for a long period of time not only tends to produce drowsiness but the variation in the time elapsing between successive responses provides an objective index of changes in subjective time perception. The time between two successive key taps—the interresponse time (IRT)—constitutes an objective measure of subjective temporal equality, inasmuch as the assigned task is to allow equal amounts of time to elapse between responses. Although from the subjective point of view the intervals are all judged to be equal, there is an objective lengthening of the intervals as the subject becomes drowsy. According to the terminology traditionally associated with studies of time perception, the drowsy subject makes negative time errors, that is, underestimates the passage of time. Under the conditions of this experiment, judgments concerning the passage of time were most accurate when mean alpha voltage was high and negative time errors were related to decreases in the voltage of this frequency. These findings are in harmony with the work of other investigators relating alpha activity to consciousness (*1, 2*).

Electroencephalographic (EEG) potentials from a transoccipital linkage (*3*) between electrodes applied to the scalp with salt paste were amplified (*4*), filtered (*5*), integrated (*6*), converted from analogue to discrete form (*7*), and cumulatively recorded (*8*). The slope of the resulting cumulative record may be interpreted as a completely objective index of brain wave activity in the frequencies passed by the filter. While each subject was alert and relaxed in the situation described below, the active band-pass filter (Q equals 10 at 3 db point) was tuned to the peak frequency of his alpha range. After this initial tuning the filter was not changed during the rest of the session.

The subjects employed in this study were 24 male university students, ranging in age from 21 to 28 years, selected for their ability to relax in the experimental situation. They were paid a moderate hourly wage for their participation in the experiment. These subjects were all good alpha generators; poor alpha generators were eliminated after a preliminary EEG examination. This selection was made solely to facilitate measurement and description of the EEG variable; there is no reason to expect that otherwise normal subjects who happen to be poor alpha generators would be unable to estimate time as well as good alpha generators.

While being tested, a subject was isolated in an air-conditioned, lightproof, sound-attenuated chamber. He lay on a comfortable bed with his preferred hand in contact with an electrically shielded telegraph key. He was instructed to keep his eyes closed and to pace his responses (key taps) as regularly as possible at intervals of approximately 3 seconds by counting silently "one, one thousand, two, one thousand, three, one thousand" and repeat, pressing the key momentarily (*9*) on each count of "three." If he failed to respond for too long a time (actually 90 seconds, but the subject was not informed how long), he was automatically alerted by means of an auditory signal delivered through a pair of earphones which he wore throughout the session. The alerting stimulus consisted of white noise from an audiogenerator (*10*) delivered in 0.1-second bursts [on-off phases controlled by an electronic switch (*10*)] at intervals of 1 second, commencing at threshold intensity and increasing 1 db with each successive burst. The subject was instructed to tap the key whenever he heard such a signal and then to continue to tap the key every 3 seconds. A single response by the subject terminated the signal instantly. The recording attenuator (*10*) controlling the intensity of the signals then automatically returned itself to the threshold setting. The subject received no information concerning the accuracy of his 3-second estimates other than the alerting signals after 90 seconds of nonresponding. This free arrangement allowed the subject to display the lability of his time estimates with minimal constraint.

Each subject was given a training session prior to the testing session; these two sessions were never less than 1 day nor more than 7 days apart. Only the data of the second, or testing, session are included in the results. Training and testing were of somewhat variable duration, ranging from 3 to 4 hours, depending upon a number of factors such as electrode failure, subject discomfort, and so forth.

The manner of recording is demonstrated in Fig. 1. The integrated EEG voltage is cumulated on the y-axis against time on the x-axis. In order to conserve space the original record has been telescoped along the x-axis (time); it may be reconstituted simply by dropping a line from the upper end of each record segment to intersect perpendicularly with the x-axis and by moving the next segment of the record to the right so that its lower end is superimposed on the point of intersection, and so forth. The key taps are represented on the record as momentary deflections. Each series of auditory signals is represented on the cumulative record as a sustained depression, indicated by an arabic numeral; the downward deflection marks the beginning of a signal series and the return to the base line marks the end.

The *entire* cumulative voltage record of each subject's test session was analyzed. Two different measures were made for each response: (i) time elapsed since the previous response, or IRT, and (ii) the mean slope of the cumulative voltage record during that IRT. The data were then tabulated into ten IRT categories and into 12 slope categories. The first nine IRT categories cover the range in 10-second intervals up to 90 seconds; the tenth IRT category contains all IRT's longer than 90 seconds. Since the auditory signal was automatically introduced at 90 seconds of nonresponding, most of the responses in the tenth IRT category may be considered to result from the prompting of the signal. Means were then computed for the slope scores in each IRT category. Finally, the means of the slope scores were normalized so that the highest value (always IRT category I) was taken as 100 percent and the means of all the other IRT categories were expressed as percentages of the score in the first category. These normalized mean scores for individual subjects are plotted as black dots in Fig. 2, and the arithmetic means of the normalized mean scores in each IRT category are connected by a heavy line.

The data presented in Fig. 2 show that the mean voltages associated with IRT categories II through X are all distinctly lower than those associated with IRT category I. In addition, there is a decremental trend beginning with category II and extending to category V or VI; the means of the means of the first six categories are fitted by a straight line on log-log coordinates, indicating that this relationship can be described by a power function. Beyond category V or VI, however, there is no definite trend in evidence. This suggests the possibility that there is more information pertaining to the further lengthening of the IRT's (VI–X) to be found in other EEG frequencies, presumably in those somewhat slower than the alert peak alpha frequency. For example, Simon and Emmons (*2*) reported that the alpha frequency for the deep drowsy state (A–) was approximately 2 cycles slower than in the alert state (O). It should be emphasized that since the band-pass filter employed in the present experiment was tuned to the peak of the alert alpha frequency distribution, this would discriminate sharply against a frequency 2 cycles slower. Furthermore, it is apparent from the Simon and Emmons study that voltage in the slower portion of the alpha range is not equivalent in its behavioral implications to voltage in the faster portion of the alpha range if alpha is defined as activity in the 8- to 13-cycle range.

Two subjects remained sufficiently alert throughout their test sessions that they required no prompting signals. While these two subjects did not generate any IRT's in the longer categories, their voltage decrements across categories I–III were similar to those exhibited by the rest of the subjects.

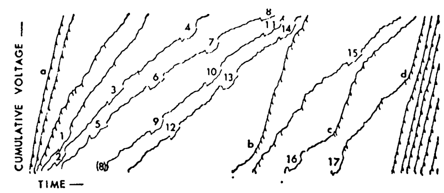

Fig. 1. Actual record of cumulative alpha voltage of EEG as a function of time. The record is telescoped (see text) along the *x*-axis (time) but the time between 9 and 10 or between 12 and 13, for example, is 90 seconds.

A few subjects became unusually drowsy in this experimental situation and had to be alerted repeatedly by auditory signals. Figure 1 shows a portion of the record obtained from one of these subjects. After an initial period of regular responding at high voltage (see "a"), there was a rapid, progressive fall in voltage and an associated lengthening of IRT's, culminating in the first signal series (see "1"). Between the second and the 14th series of signals the subject did little more than respond when prompted; during this time his alpha voltage was low—about one-fourth of the initial voltage in the test session. After the 14th signal series the subject returned for a while to spontaneous responding (see "b") and exhibited an associated sharp rise in alpha voltage. Then his alpha voltage fell again, IRT's lengthened, and three more signal series ("15" to "17") were required to elicit responding. There followed a long period of fairly steady spontaneous responding associated with high-voltage alpha (beginning at "d"). At times the changes in voltage and responding were of an abrupt "off-on" character (as at "c" and "d") whereas at other times the voltage and behavioral changes were more smoothly modulated. When asked at the end of the test session how many times the signals had alerted him this subject replied, "I guess you caught me napping two or three times." Subsequent experimental probing of similar behavior seems to support the view that signal series which are not immediately followed by high-voltage alpha activity and spontaneous responding have a low probability of recall. It is possible that this finding is related to the observations of Dement and Kleitman (*11*) that dreams tend to be forgotten unless interrupted or closely followed by periods of wakefulness.

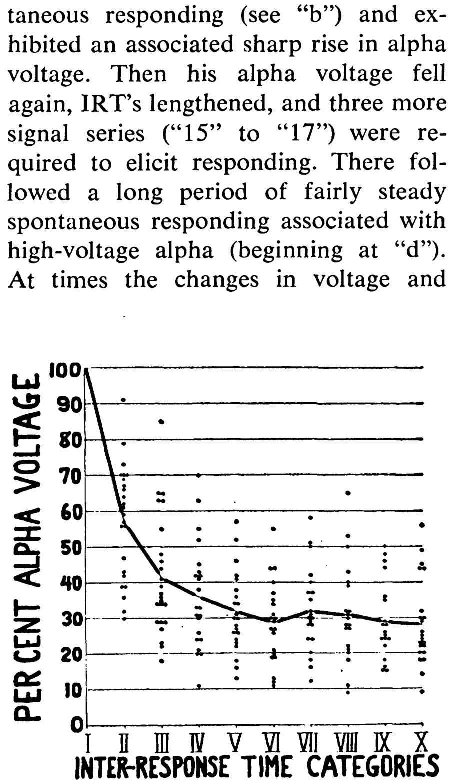

Fig. 2. Alpha voltage of the EEG as a function of the time between responses.

Subjects also reported that two distinct subjective impressions were elicited by the auditory signals: (i) a state of subjective confusion and search *preceding the response*, during which the subject tried to remember where he was and what it was he was supposed to be doing, and (ii) a more oriented response in which subjective impressions ("What happened?" "What was that?" "I must have dozed off." "My mind must have wandered.") *followed* the key tap which terminated the signal series. Whether such responses can be differentiated on the basis of EEG records poses an interesting but difficult experimental problem.

It should be pointed out that a decrease in alpha voltage may be associated with either an increase in voltage of slower frequencies in the case of drowsiness or an increase in the activity of higher frequencies in the case of intense concentration or attention. The method of EEG analysis described in the present report does not distinguish between these two conditions because it ignores voltage changes in non-alpha frequencies. However, the relaxing conditions of the present experiment were designed to favor the induction of drowsiness and provide virtually no cause for intense concentration. The relationship between alpha voltage and timing behavior described in this report covers only the range of consciousness between "very drowsy" and "relaxed, alert." The effect of more intense alertness (with associated desynchronization of the EEG to low voltage, fast activity) upon timing behavior would be far more difficult to assess because of the great variety of possible behavioral concomitants; for example, intense concentration on the timing task might enhance timing accuracy, whereas concentration on anything else would probably interfere with it. By contrast, the behavioral correlates of drowsiness are much simpler.

The chief significance of the present study lies in the demonstration of a positive relationship between two continuous variables, one of which is physiological (alpha voltage) and the other psychological (accuracy of time perception). Presumably, this represents a way in which the quantitative physiological psychology of consciousness can be advanced beyond the limitations of arbitrarily defined "stages." While these data might tempt some to speculate about the "slowing of a neural clock," it would seem that the deterioration of perception and memory associated with a decrease in quality and quantity of alpha activity reported by Simon and Emmons (*2*) for conditions of drowsiness is sufficient to account for the errors in time perception observed in the present study (*12*).

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References and Notes

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2. C. W. Simon and W. H. Emmons, *Science* **124**, 1066 (1956).
3. Since localization was not the primary goal of this experimental study, the transoccipital linkage (between right and left occipital electrodes) was selected.
4. Electroencephalograph, model III-D, Grass Instrument Co., Quincy, Mass.
5. H. C. Becker, W. A. Mickle, R. G. Heath, *Electroencephalog. Clin. Neurophysiol.* **10**, 731 (1958).
6. Operational amplifier, model K2-W, George A. Philbrick Researches, Boston, Mass.
7. Analogue-to-discrete data conversion: a circuit provided for the momentary operation of a relay whenever an arbitrarily selected level of voltage integration was reached. The operation of the relay provided an output pulse and re-set the integrator to zero voltage.
8. Harvard cumulative recorder, Ralph Gerbrands Co., Arlington, Mass.
9. Only the initial key depression produced a pulse in the control circuit, so that holding the key down had no further effect. In order to make another response the subject had to release the key and press it again.
10. Noise generator, model 901; electronic switch, model 829B; recording attenuator, model E3262A; all by the Grason-Stadler Co., W. Concord, Mass.

W. Dement and N. Kleitman, *J. Exptl. Psychol.* **53**, 339 (1957).

12. Supported in part by research grant A.F. 49-(638)-98 from the Air Research and Development Command, Department of the Air Force, and in part by PHS research grants MY-2971 and MY-00987 from the National Institute of Mental Health. The constant support and helpful criticism of Dr. Henry K. Beecher, in whose laboratory this research was conducted, are gratefully acknowledged. Much guidance on neurophysiological matters was graciously provided by Dr. Mary A. B. Brazier. I am also indebted to Melvin Meister for technical assistance.

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Redundancy in Children's Texts

Abstract. *The sequential constraints of pairs of letters were computed for a series of graded readers. Information in single letters is about the same for all texts. Redundancy decreases with increasing grade in a regular way, while mean word length increases. A third reader has about the same redundancy as simple adult text. The constraints in a first reader are considerable, whereas those in a fifth reader approach those in average adult text.*

There is good evidence that letter redundancy is a powerful determinant of the learning of verbal materials (*1*) and of the reconstruction of mutilated texts (*2*). That such contextual constraints affect the learning of similar material by children has been shown also (*3*). The application of information theory to the sequential constraints among the letters has permitted quantification of the letter redundancy in texts of varying difficulty (*4*). Children's graded readers are written on the assumption that a small initial vocabulary, increasing within a reader and within a series, yields texts that become progressively more difficult. If this is true, then sequential constraints should decrease as the difficulty of the reader increases. As a first step toward quantification of language development in children, reading texts at levels 1, 2, 3, and 5 were compared with each other and with texts intended for adults.

We have measured letter redundancy by using a slight modification of Newman and Waugh's (*4*) method. Our modification gives more precise estimates because of more extensive tables of $\log_2$ and addition of the Miller-Madow (*5*) bias correction for sample size computed at each stage in a sequence. Contingency tables were constructed, each of which showed the number of times that a given symbol was followed at step n to the right by every possible symbol, where n takes on the values 1, 2 . . . , n. The number of symbols, a, was 28—the 26 letters of the English alphabet plus the space (for word length) and period (for sentence length). From these contingency tables, calculations were made of

$$H = -\sum_{i=1}^{a} p(i)\ \log_2 p(i) \qquad (1)$$

in which H is the amount of information in bits and $p(i)$ is the probability associated with each of the alternative symbols. This is just the information contained in letters according to their relative frequency of occurrence, which we write hereafter as $H(1)$. The amount of information found in pairs of adjacent items, i and j, in a sequence is $H(i, j)$, where

$$H(i, j) = -\sum_i\sum_j p(i, j)\log_2 p(i, j). \qquad (2)$$

If row and column selections were made independently, then a given table would contain twice the amount of information computed for single letters. The information added by the second letter of the pair when the first is known, $H_1(2)$, is:

$$H_1(2) = H(1, 2) - H(1) \qquad (3a)$$

or, more generally, the amount of information which is added by the nth letter of a sequence of n letters when the first is known, $H_1(n)$, is:

$$H_1(n) = H(1, n) - H(1). \qquad (3b)$$

McGill and Garner (*6*) define a quantity, T, the conditional information in a second letter that is dependent on the choice of a first letter

$$T(1, n) = 2H(1) - H(1, n). \qquad (4)$$

The information in the last letter of a sequence $F(n)$, may be approximated (neglecting interaction terms) as

$$F(n) = H(1) - \sum_{k=1}^{n} T(1,k). \qquad (5)$$

Finally, the relative sequential constraint in a sequence of n letters, C_n is given by

$$C_n = \frac{\sum_{k=2}^{n} T(1, k)}{H(1)}. \qquad (6)$$

Appropriate information measures were computed to determine the constraints between all pairs of letters at distances of the second letter from the first of 2, 3, . . . , 12, 30, 60, and 120.

Table 1 shows that constraint increases regularly from the *Atlantic Monthly* to the First Reader, with the Bible being about as constrained as the Third Reader, and the Fifth Reader approaching average adult text (*7*). This is true whether only the constraint of adjacent pairs is considered or whether the constraint between the first and last letters in sequences of 11 letters is considered. The relative rank ordering of C_1 and C_{11} contains but one reversal, the Bible, which is a peculiar text in terms of repetitiveness of words of low frequency in Modern English and also is represented by a small sample (*8*). $H(1)$ is about the same for all texts,