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TWO MEASURES OF E.E.G. VARIABILITY

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It is axiomatic that the EEG of a human varies in amplitude from moment to moment; but it is difficult to measure this variation because of the differences in amplitude variations between individuals, and even within a single individual, over time. The major question seems to center on the selection of an appropriate "time base" for comparing successive variations in amplitude. Goldstein & Beck (1965) noted in their review that analyses of a short sample of the EEG record could be misleading because of the extreme variability of the EEG over time. The choice of 30 successive intervals of 20 seconds each has been chosen primarily because of consistency between individuals in a group over time. Goldstein et al. (1965) reported a seven day test-retest reliability of the coefficient of variation (CV) of 0.70 ($N=16$) for normals and 0.94 ($N=16$) for schizophrenics when the 20 second time base was used. Marjerrison, Krause & Keoph (1968)

repeated the method used by Goldstein et al. (1963, 1965) and found that the rank order correlation of the CV's in a schizophrenic group over a 3 month time was 0.64 ($N=10$). Despite these results it is possible that this time base is too long to measure the rather fleeting changes seen in the EEG.

The purpose of this study was to measure the test-retest reliability of the CV, as measured by Goldstein et al. (1963, 1965) and Marjerrison (1968) and to investigate a new method of measuring quantitative EEG variability over time with a much smaller time base.

METHODS

The EEGs of 50 paid normal males (ages 17 through 62), about high school educational level, were individually recorded. Each session lasted 15 min and was held in a sound-attenuated room with *S* in a supine position, eyes closed. A solid-state integrator and a Beckman-Offner Type R Polygraph were used to record the EEG from a left occipital electrode with reference to both ears. Paper speed was 30 mm per second. Continuous records during 15 min prestress, one min stress (placement of a foot in ice and water; cold pressor), and 15 min poststress were recorded. One record was analyzed

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TABLE 1

	Prestress		Poststress	
	CV (.100)	CVT (.100)	CV (.100)	CVT (.100)
Mean	17.07	26.88	15.44	27.67
Standard Deviation	10.56	8.32	9.25	9.57
	Mean prestress record time =53.76 seconds		Mean poststress record time =55.34 seconds	

Means and standard deviations for the CV and CVT scores for each condition ($N=50$) calculated from 60 successive measurements of integrated EEG.

statistically before the cold pressor (prestress) and one record was analyzed after the cold pressor (poststress).

The Coefficient of Variation (CV)

The integrator pulses were summed for each 20 sec period; artifacts were noted visually and deleted from the digital data. The mean integrated amplitude (MIA) and standard deviation (SD) were obtained from 30 successive 20 sec periods except for necessary deletions. The coefficient of variability (CV), a measure of variability that allows comparisons to be made among individuals of differing MIA values, was calculated by dividing the SD by the MIA.

The Coefficient of Temporal Variability (CVT)

Von Neumann, Kent, Bellinson & Hart (1941) have suggested a measure of temporal variability called the mean square successive difference (delta squared). Since delta squared is similar to sigma squared (variance), the temporal measurement analogous to the CV would be the CVT, i.e., the square root of the mean square successive difference divided by the mean. The method was to measure the distance in mms between five pulses of the integrated record. Sixty such successive intervals were measured and this series produced the CVT score for each individual. The sensitivity in the electronic system was constant for all subjects, so that a person with a low amplitude EEG required more time to produce a record than one with a high amplitude. The relationship, if the same series of intervals is used, between the CVT and CV is: $CVT = CV \sqrt{2-2RA}$ (where RA=autocorrelation, lag one).

RESULTS

The product moment correlation between the pre- and poststress conditions for the CV values was $+0.35$ ($df=47$, $p<.05$). The product moment correlation between the pre- and

poststress conditions for the CVT was $+0.63$ ($df=48$, $p<.01$). These two correlations are significantly different from one another ($z=1.81$, $p<.05$). The means and standard deviations of each measurement are presented in Table 1.

DISCUSSION

While the data show significant association of the CVs from condition to condition, a more consistent measure of variability in the EEG is the CVT. It should be noted that while the CVT is taken from a much shorter time span—mean time for 60 successive measurements about 53 sec in the prestress condition, and about 55 seconds in the poststress condition—there is a higher significant correlation within the group than found in the ten minute records with 20 seconds as a time base. It should also be noted that although the CVT was calculated from data *included* in the CV record, the associations between these two measures of variability for each condition were not significantly related. It would seem possible through inspection of the record (see Fig. 1) that the most descriptive patterning of the analog record is described by the measurement of amplitude change which uses a much shorter time base. Fig. 1 illustrates the intervals of measurement used for the CVT by numbers one, two, three, four, and five. Sixty such successive intervals would produce one record. Sensitivity of the analog-to-digital data was kept constant for all subjects and it is obvious that the distance between pulses is a function of the sensitivity of the integrator. That is, the integrator could have been set to produce one pulse where five were produced in this study. The shortest and low-

FIG. 1. Analog EEG and the method of measurement of digital data from concurrent integration for the CVT scores.

est alpha burst among our records seemed to produce 5 pulses at our sensitivity. Since an alpha burst could be thought of as the basis of EEG information, the choice of an interval of 5 pulses was chosen. It should be remembered that the duration and amplitude of alpha bursts, both between and within individuals, varies greatly. In view of this, it is remarkable that such strong test—retest correlation was obtained.

In the inspection of "rest" records of normals, it becomes apparent that a normal subject, lying on his back and with his eyes closed, tends to drift from wakefulness into either stage one or stage two sleep within 10 to 20 minutes. The cold pressor, interjected between the two 15 minute sessions, assured that all subjects were awake at the onset of measurements of each session. The type of variability measured by the 10 minute resting record might primarily reflect a shift from the wakeful record to stage one sleep. The shorter record (the series used for the calculation of the CVT here) is much more likely to be a measure of either wakefulness or a particular stage of sleep. Most of the CVTs of the prestress condition were taken from the end of the resting record and are stage one sleep EEG patterns (relatively low voltage, mixed frequency). Most of the CVTs of post-stress condition were taken from the first part of the poststress period and are wakeful records (alpha present in most of them). The reliability of the CVT, then, presents not only the reliability of a group during a wakeful record,

but also the stability of the member of the group from one state of behavior to another in terms of EEG amplitude variability.

So far we have discussed methodology which is related to the objective measurement of the EEG. Psychology has repeatedly sought a reliable electrophysiological measurement to correlate with behavior. Clark L. Hull, for example, postulated that: "Reaction potential may be inferred from reaction amplitude. In the case of the Tarchanoff galvanic skin reaction in man, the relationship between reaction potential and amplitude is a linear one" (Hilgard, 1956). H. J. Eysenck has suggested a "Stratification Theory" within which physiological factors were included (Franks, Holden & Phillips, 1961). What are the possible psychological merits of using the CVT in interpreting EEG data in relation to overt behavior or consciousness? In this paper we have investigated fields of study related to neurology, psychiatry, pharmacology, mathematics, and psychophysiology with one goal in mind; that is, to find out the most reliable objective measurement (or the one with the least "error", if it is seen that way) of central nervous system function that differentiates one individual from another. Furthermore, the emphasis of the utility of this differentiation is in terms of behavior (normal group vs schizophrenic group) or altered states of consciousness (or behavior) produced by various pharmacological compounds. The psychologist may see his major role as the description of behavior, and while

this paper does not use classical psychological measures such as the M.M.P.I., it explores an objective technique which could produce scores characteristic of both individuals and groups, and which could be used to establish more concrete concurrent validity for particular paper and pencil measurements. The CV measure of EEG variability has been used successfully for some time for the evaluation of drug effects by researchers in the New Jersey Bureau of Research in Neurology and Psychiatry. The CVT is an attempt to incorporate the time linked quality of the EEG into a related measurement. Only future research will determine whether this related but new dimension of EEG activity is correlated to various accepted psychological scales.

The shorter series method of variability measurement might be the subject of research relating amplitude variability to change in frequency of the EEG. Pilot work confirms that the CVT series discussed in this paper produces increased scores for a downward shift in frequency if the amplitude is held constant. Former work (Burdick, 1968b) showed no relationship between the alpha frequency and amplitude variability of the longer time base, although an association between them had been expected.

The use of a series sensitive statistical measure such as the CVT, with a time linked series of "R" to "R" intervals (EKG), suggests that this procedure could be used in an automatic computer analysis of many types of learning or repeated measurements performance data. The CVT calculated on wakeful "R" to "R" intervals correlated highly with various modes of scoring cardiac lability (Burdick, 1968). While the wakeful CVT of the EKG has shown little or no relationship with EEG measures (Burdick & Scarbrough, 1968) both the CVT of the EKG and the CVT of the integrated EEG have produced interesting data on sleep behavior (Goldstein, Burdick & Laszlo, in press). It is in the exploration of sleeping behavior that the psychologist becomes increasingly dependent on objective electronic measurements to explore this deceptively "passive" state of consciousness. Presently, our laboratory is exploring

both the sleeping and wakeful EEG and EKG to define effects on an alcoholic population. This present work will include many psychological scales and performance tasks which may help establish correlates of this method of scoring electrophysiological activity.

SUMMARY

A previously reported measure of amplitude variability in the wakeful EEG (the coefficient of variation, CV) using a 20 second time base and a recently developed temporal measure (the coefficient of temporal variability (CVT) using a much shorter time base, were calculated from EEG records of 50 normal males) before and after a cold pressor stress of one minute. Pre and post conditions were analyzed so that the correlations for each measure of EEG variability could be compared and the association of each could be evaluated under each condition. While both the CV and CVT of these two different series were reliable at the 0.05 level; the CVT was significantly more reliable than the CV. The two measures were not significantly related to each other. It was suggested that the more descriptive and reliable patterning of the CVT series be used to explore the relationship of EEG frequency to EEG amplitude variability and that this measure of EEG variation be compared to similar measurements of variation in other physiological systems that are known to have behavioral correlates.

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