RESEARCH OBJECTIVES AND SUMMARY OF RESEARCH

The major concern of the Communications Biophysics Group remains the search for a better understanding of sensory communication, in particular, of hearing. As in the past, future research will tend to combine electrophysiological and behavioral experiments with machine data processing and analytical methods from communication theory.

The principal activities of the group, at present, include the following areas of research.

1. Studies of isolated peripheral nerve fibers under electrical stimulation, with emphasis on recovery characteristics and apparently random behavior.
2. Experiments on the effects of the efferent olivo-cochlear bundle on the activity in the auditory nerve of anesthetized cats.
3. Further study of the alterations on evoked potentials produced through conditioning procedure in the rat.
4. Studies of the effects of sleep upon the electrical activity of the nervous system.
5. Studies of various mathematical models intended to describe the behavior of single nerve cells in the auditory nerve and in the cochlear nucleus.

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6. Further psychophysical experiments related to various interaural effects and models.

7. A variety of studies of the electrical activity of chick embryo brain tissue in vitro.

3. Changes in the PST histograms of cortical neurons in response to the second of two successive sensory stimuli.

Experiments will also be carried out at the Eaton-Peabody Laboratory of the Massachusetts Eye and Ear Infirmary, in Boston, by staff members holding appointments in both institutions. Included in this category are the following research projects.

1. Further studies of the movements of the bones in the middle ear.

2. Experiments in which microelectrodes are used to record various potentials inside the cochlea.

3. Continued research on the electrophysiological characteristics of single neural units in the cochlear nucleus and in the auditory nerve.

The principal completed research contributions of the group, during the past year, can be summarized as follows.

(a) Physiological Studies. Electrical stimulation of the crossed efferent olivo-cochlear bundle in anesthetized cats has little effect on the gross auditory nerve responses to high-intensity clicks.

Studies of the spontaneous and continuously stimulated activity of single units in the cochlear nucleus have been carried out under a variety of conditions. Interesting interrelations and correlations with anatomical location of the unit have been observed.

Single-unit activity in the eighth nerve of the green frog has been studied, and the results compared with similar published observations on the bullfrog.

Optical measurements of movements in the middle ear have given a reasonably accurate transfer function for the opened middle ear of anesthetized cats. Experiments are being continued to determine the errors introduced by the opening of the middle-ear cavity.

(b) Psychophysical and Behavioral Studies. The calling behavior of bullfrogs evoked by various natural and artificial sound stimuli has been studied in detail. The results correlate nicely with published physiological observations.

Several aspects of binaural masking have been studied and the results incorporated into a model of increasing scope.

(c) Mathematical Models. Several stochastic models of the spike activity in primary auditory neurons have been developed, and some of the corresponding implications for behavioral discrimination limits have been computed and compared with psychophysical data.

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background spontaneous alpha rhythm, the waves of the rhythmic afterdischarge have been clearly distinguished from the spontaneous rhythms by appropriate statistical tests. Moreover, it has been noted that alterations in the background EEG occurring in unilateral disease of the brain may be accompanied by similar alterations, on the affected side, in the evoked responses to flashes.

The present report extends the exploration (in pathological states) of the relationship between induced and background rhythms. Results are described from two patients with two different types of disorder, hypothyroidism and hypercapneic encephalopathy.

In Fig. XXV-1 portions of the parieto-occipital EEG from a patient with severe hypothyroidism before the beginning of thyroid therapy, and six, ten, and forty-one days after initiation of therapy are shown. Autocorrelograms and averaged responses for magnetic tape recordings on the three later dates are shown in Fig. XXV-2. The progressive change in the EEG from that of very slow (i.e., low-frequency) irregular waves to the normal EEG is quite apparent from inspection of Fig. XXV-1. In Fig. XXV-2, in the autocorrelogram of April 3rd, 1964, the presence of a minor peak at 200-msec delay (corresponding to an averaged frequency of 5/sec) is indicative of the average period of the irregular waves in the EEG of that date. The autocorrelogram for April 7, 1964 (10 days after initiation of therapy) indicates the presence of irregular activity with an averaged frequency of 8/sec. One month later (May 8, 1964) the averaged frequency has increased to 8.8/sec; but of equal or greater interest is the fact that the EEG activity on the last date is much more rhythmic than previously, as evidenced by the much more gradual decrement of the successive peaks in the correlogram.

From inspection of the averaged response to photic stimulation which is shown on the right in Fig. XXV-2, it is apparent that for the recording of April 3, 1964 (six days after the initiation of therapy) no rhythmic afterdischarge follows the early components occupying the first 275 msec of the response. The last complex is also apparent in the averaged response one month later on May 8, 1964, but the latency of all components has been decreased proportionately, approximately 20 per cent. More striking, in comparison with the earlier averaged response, is the presence in the last one of a prominent rhythmic afterdischarge, the frequency of which is the same as that of the background EEG, as evidenced by the autocorrelogram on the left. (A recording with photic stimulation was not possible on April 7, 1964.)

Of considerable interest in comparison with these electrographic results are observations on this patient's mental status. Before initiation of therapy he was observed to be markedly somnolent. Following initiation of therapy (on March 28, 1964), evidence of decreasing somnolence was apparent almost within a day. Upon detailed psychometric evaluation on March 31st, which was carried out by the cortical function test laboratory of the Neurology Service (three days after initiation of therapy), it was found that the patient was still barely responsive for complex tests, and hence
no general test scores could be obtained. For example, he was unable to recite the alphabet or to provide personal information, and was disoriented with respect to time and place. Not only was his attention span very limited, but he was generally uncooperative and at times even somewhat belligerent. (During the EEG recordings of March 26th and April 3rd, he was alerted constantly.)

His mental status continued to improve, however, and was clinically observed to be essentially normal at the time of the EEG recording of May 8, 1964. This finding was confirmed upon follow-up psychometric evaluation on August 5, 1964. Cortical function test at that time, in comparison with the earlier test, disclosed that his performance was strikingly improved. He was cooperative and responded immediately and appropriately to questions. He conversed at length about his illness and his former work experiences. From these results, it is apparent that there were striking changes both in the electrographic findings and in higher mental functions, following therapy of the hypothyroid state. Although changes in the characteristics of the EEG following therapy of hypothyroidism are well known (see, for example, Ross et al.3 and Hermann4) the present study has afforded an additional opportunity to explore the effect on the rhythmic afterdischarge to flashes in relation to the background EEG.

Electrographic and psychometric findings from the second patient provide a striking contrast with those described above. The diagnosis in the second patient was that of hypercapneic encephalopathy, in which abnormally high levels of blood carbon dioxide resulted from chronic pulmonary insufficiency. The EEG and autocorrelograms for this patient are shown in Figs. XXV-3 and XXV-4. The parieto-occipital EEG is characterized by essentially completely random activity, no periodic rhythm being at all evident. Correspondingly, the autocorrelogram presents the appearance of that of low-frequency noise and shows no periodic components. The averaged response to photic stimulation is rather similar in form to that for the recording of April 3, 1964 on the hypothyroid patient (Fig. XXV-2); the latencies for the several components in Fig. XXV-4, however, are appreciably longer than those in Fig. XXV-2. Following the components of the evoked response occupying the first 350 msec, there is no subsequent rhythmic afterdischarge.

Despite the above-described electrographic findings, the patient's mental status, as determined by psychometric tests immediately following the EEG recordings, was remarkably good. Thus, mental ability, measured by verbal tests, was rated as upper average and his memory was rated above average for his age. He was generally conversant with current events, and his general information covered a very wide range. In brief, there was no marked impairment of mentation.

Unfortunately, this patient did not survive the illness, and hence it was impossible to search for a possible reappearance of the rhythmic afterdischarge to flash as a concomitant to improvement in the clinical EEG, which can follow correction of the disordered metabolic state in this disease.5,6 Despite the lack of follow-up recording in the present
Fig. XXV-1. EEG recordings from a patient with hypothyroidism before, and at various times after, initiation of thyroid therapy. (Treatment began on March 28, 1964.)

Fig. XXV-2. Autocorrelograms and averaged responses for the EEG recordings of Fig. XXV-1.

Fig. XXV-3. EEG from a patient with hypercapneic encephalopathy.

Fig. XXV-4. Autocorrelogram and averaged response for the EEG recordings of Fig. XXV-3.
instance, it is quite evident that the metabolic disorder that gave rise to the electrographic abnormalities did not affect higher mental functions to the same degree.

The findings from these two patients, with different types of metabolic disorders, contrast strikingly with respect to the divergence between their electrographic and mental functions. For the first patient, the hypothyroid state evidently had affected both EEG and mentation to an appreciable degree, therapy of the hypothyroid state being followed by return to normal of both EEG and mental function. On the other hand, for the second patient, the electrographic abnormalities were disproportionately greater than those of mentation. The last finding indicates that caution must be exercised in inferring the level of higher mental functions from the EEG picture.

The role (if any) of the rhythmic afterdischarge in relation to higher mental functions obviously remains a subject for further research; the present findings provide groundwork upon which further speculation in this area can be based.

For further study of relationships between electrographic findings and mentation, recordings from other types of metabolic disorders are planned. Additional types of analysis of data are also contemplated. Dr. Raymond Adams, Chief of the Neurology Service of the Massachusetts General Hospital, has raised the question of whether or not the degree of synchrony of the EEG from the two hemispheres might not provide some additional data for this general problem. In this connection, it is of interest that in studies in normal individuals, a large degree of synchrony of the EEG from homologous locations in the parieto-occipital region has invariably been found. Even in the presence of unilateral EEG abnormalities of the slow-wave type an appreciable content of synchronous components has been found. It will therefore be of considerable interest to explore, with the aid of these quantitative techniques, the question of bilateral synchrony of the EEG in patients with metabolic disorders of various types, and the relationship of these findings to results of psychometric tests.

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J. S. Barlow

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B. CROSSCORRELATION OF ACCELEROMETRIC RECORDINGS OF MOVEMENT DISORDERS IN MAN

For patients with movement disorders in both upper extremities (for example, tremors of the "cerebellar" type, and of the Parkinson type), the degree of synchrony or asynchrony between the two sides is of considerable practical importance. Thus, in those instances in which the tremor is asynchronous, the patient may be able to stabilize both limbs by clasping one hand with the other, and hence may be able to pick up an object with as great a degree of steadiness as could be accomplished with either hand alone. Contrariwise, if the tremor on the two sides is synchronous, or largely synchronous, then the above-described maneuver will be of little benefit.

Dr. Robert S. Schwab, a neurologist at the Massachusetts General Hospital, in making these points, has observed that bilateral tremors tend to be synchronous in Parkinson's Disease, whereas they tend to be asynchronous in tremors of the cerebellar or cerebellar-familial type. He also raised the question of whether correlation techniques, applied to tremor recordings, might not provide further data on this question. The
present report describes some results from recordings of tremors in a small series of patients and compares them with similar recordings from normal controls.

Movement was monitored accelerometrically with the aid of two Model SPA-1 accelerometers manufactured by the Grass Instrument Company. Simultaneous recordings onto paper and onto magnetic tape were made with the aid of a Grass Model 5 Polygraph. The accelerometers were secured with tape to the dorsal surface of the hand (or finger), the sensitive direction of the accelerometers being vertically oriented.

Accelerometric recordings of movement, in contrast to techniques of recording of position of a limb or finger, are of very great advantage for the recording of severe tremors. This advantage results from the absence, with this technique, of spatial limitations that would necessarily be imposed on the range of movement if position per se were recorded. Moreover, complete freedom of movement in any direction is possible, the accelerometer sensing only those components of movement which are in its sensitive orientation. It should be noted, of course, that accelerometric recordings provide the second derivative of position from which the position itself could be obtained by double integration, if it were desired. In these studies in which the degree of synchrony of movement on the two sides is being studied, recordings of acceleration per se have proved quite satisfactory.

In Figs. XXV-5 - XXV-7, analyses of tremor recordings from a patient with Parkinson's disease are shown, together with brief excerpts from the corresponding inked traces. For the recording shown in Fig. XXV-5, both accelerometers were mounted on the right hand, which rested on the right knee. This recording thus simulates results that would be obtained, were identical tremors present on the two sides. The outputs of the two accelerometers are seen to be essentially identical, as are the two autocorrelograms. In all of the autocorrelograms of this series, the gains of the correlator have been set so as to give a deflection at zero delay of 4 units on the chart paper. For computation of all the crosscorrelograms, the gain settings of the computer were chosen as the mean (in db units) of the gain settings used for the corresponding autocorrelograms. By means of this system of normalization, the crosscorrelation coefficient can be obtained directly from inspection of the crosscorrelogram.

In Fig. XXV-5, the peak of the crosscorrelogram, which occurs at zero delay, is of the same amplitude as the two autocorrelograms, and hence the crosscorrelation coefficient in this instance is 1.0. The frequency of the tremor is approximately 3.3/sec. Simultaneous recordings from the two resting upper limbs are shown in Fig. XXV-6, and it is apparent from the autocorrelograms that the frequencies on the two sides are slightly different, 3.8/sec on the left, and 3.3/sec on the right. The crosscorrelation coefficient is seen from the crosscorrelogram to be 0.32. The frequency of the component common to the two sides is 3.5/sec, which is intermediate in value between the frequencies on the two sides.
Fig. XXV-5. Accelerometric recordings and correlograms for a patient (J. F.) with Parkinson's disease. Both accelerometers were mounted on the dorsal (upper) surface of the left hand, to simulate results of bilaterally identical tremors. The sensitive direction of the accelerometers was vertical, the hand resting lightly on the knee. The calibration is in terms of g, the acceleration caused by gravity. Duration of analyzed recording, 4 minutes.
Fig. XXV-6. Comparison of resting tremors of left and right upper extremities of the patient of Fig. XXV-5 (J. F.).

Fig. XXV-7. Comparison of the left-sided tremor of patient J. F. with a simulated tremor from a normal subject.
In order to simulate results for completely independent tremors on the two sides, the patient's tremor on the right side was recorded simultaneously with a "tremor" simulated by a normal subject, and the results are shown in Fig. XXV-7. The average frequencies of the two tremors are only slightly different, 3.3 and 3.2/sec for the normal subject and for the patient, respectively. Since the two tremors are completely independent, the residual crosscorrelation coefficient of 0.1, which is evident from the crosscorrelogram, is to be ascribed entirely to sampling artefact, and it would diminish progressively with progressively longer recordings.

Results of recordings from another patient with Parkinson's disease and bilateral tremor are shown in Figs. XXV-8 and XXV-9. In Fig. XXV-8, the recordings from the two upper resting limbs are compared, and it is apparent from the autocorrelograms that their average frequencies are close, but not identical: 4.3/sec on the left, and 4.4/sec on the right. The crosscorrelation coefficient is seen from the crosscorrelogram to be 0.25. It is also apparent, from the shift of the first peak to the right of zero delay, that the left-sided tremor leads that on the right side very slightly, by approximately 50 msec. Of additional interest in the crosscorrelogram is the fact that the decrement in amplitude with increasing positive or negative values of delay, is more gradual than the decrements of the two autocorrelograms. This finding suggests that the modulation of amplitude of the tremor on the two sides is independent to some degree, a characteristic that can be seen in retrospect from inspection of the ink trace in Fig. XXV-8.

In Fig. XXV-9, this patient's tremor is compared with one simulated by a normal subject. The average frequencies are 4.3/sec for the patient, and 4.5/sec for the normal control. The crosscorrelation coefficient of 0.05 results entirely from sampling artefact.

For comparison of the above-described results from tremors of the Parkinson type, results of recordings from patients with "cerebellar" tremors are shown in Figs. XXV-10 to XXV-15. In Fig. XXV-10, for the first of these two patients, the motion of the two outstretched, unsupported limbs is compared. It is evident from the autocorrelograms that the average frequency on the two sides is markedly different, 1.5/sec on the left, and 5/sec on the right, respectively. In addition to the 5/sec component on the right side, however, there is an additional slower component, the frequency of which appears to be somewhat the same as that on the left side. It is this component that is reflected in the crosscorrelogram, with a crosscorrelation coefficient of approximately 0.37. The presence of this component in the original ink trace in the figure on the right side is not readily apparent.

In contrast to the marked dissimilarity between the frequencies for the outstretched, unsupported upper limbs, the tremor frequency on the two sides becomes much the same if the arms are supported midway between the elbow and the wrist; the results for this recording are shown in Fig. XXV-11. From inspection of the autocorrelograms, the
Fig. XXV-8. Tremograms from a patient (B.J.) with bilateral Parkinson's type of tremor.

Fig. XXV-9. Comparison of the left-sided tremor of patient B.J. with a simulated tremor from a normal subject.
Fig. XXV-10. Accelerometric recordings of "cerebellar" type of intention tremor from patient A. K. Upper extremities in the outstretched position were unsupported.

Fig. XXV-11. Recordings from the patient of Fig. XXV-10 (A. K.) of the outstretched upper extremities, supported midway between the elbows and the wrists.
average frequencies are 3.7/sec on the left and 4/sec on the right. The crosscorrelation coefficient is seen to be 0.30. The frequency of the component common to the two sides is 3.8/sec, intermediate between the average frequencies for the two sides separately. The presence of such a common component is not at all readily apparent from inspection of the original ink trace.

It is of interest, with respect to the direction of gravity on the characteristics of the tremors, that when the upper extremities are supported midway between the elbow and wrist and the wrists are oriented vertically (Fig. XXV-12) rather than horizontally, the frequency of the tremor on the two sides remains very much the same as in the horizontal orientation of the wrist. The tremor oscillations, however, are somewhat more highly damped, in the latter instance, as evidenced by the slower decrement of the interval of the two autocorrelograms in Fig. XXV-12, as compared with those in Fig. XXV-11. For the hands with the wrists in the vertically oriented position, the tremor frequencies are 3.5/sec and 3.4/sec on the left and right, respectively. The crosscorrelation coefficient for the two sides remains the same approximately as that for the horizontally oriented wrist; in Fig. XXV-12 it is seen to be 0.40. In the latter instance, the tremor on the left side leads that on the right side slightly, by approximately 40 msec, for the component that is common to the two sides.

Of additional interest in this patient was the presence of an involuntary movement of the left index finger, which is shown in Fig. XXV-13a. The movement, resembling that of a myoclonic jerk, results in an autocorrelogram, as shown in Fig. XXV-13b, with a very rapid decrement. The presence of a low peak in the autocorrelogram, at a delay of approximately 300 msec is of interest, however, for such a component raises the question of whether or not the tremor of the finger contains a component similar to that of the supported, outstretched limbs (Figs. XXV-11 and XXV-12). Such an appearance of the autocorrelogram could also possibly arise from the autocorrelation of the sharp, myoclonic jerks, if the average interval between the latter were about 300 msec. Since it was clearly not feasible to examine the question of a common component in tremor of wrist with tremor of finger by simultaneous accelerometric recordings, (for the former would be detected by the accelerometer for the latter, in addition to the myoclonic jerks), other means of exploring this possibility were carried out. For this purpose, the accelerometric signal of Fig. XXV-13 was passed through a clipping circuit in two different ways. In the first, only the sharp transients arising from the myoclonic jerks were present at the output; the autocorrelogram for this signal is shown in Fig. XXV-13c. In the second instance, the signal was clipped in such a way that the myoclonic jerks themselves were largely eliminated, so that primarily the lower frequency components of the base line in Fig. XXV-13a were available at the output; the autocorrelogram for this modified signal is shown in Fig. XXV-13d. In comparison with the autocorrelogram of the unaltered signal (Fig. XXV-13b) the questionable slow component is less prominent,
Fig. XXV-12. Recordings similar to those shown in Fig. XXV-11, except that the wrists were vertically (instead of horizontally) oriented. The accelerometers thus sensed acceleration in the horizontal direction.
Fig. XXV-13. Recordings of the movement disorder of the left index finger of patient A.K. (a) Portion of the inked trace. (b) Autocorrelogram of the unaltered tremogram. (c) Autocorrelogram of tremogram after positive clipping at approximately the level indicated by the dashed line in (a), to remove a major portion of the sharp positive peaks arising from the myoclonic jerks in (a). (d) Autocorrelogram of tremogram after positive clipping at the level indicated by the dashed line in (a), so that the signal after clipping consisted largely of the myoclonic jerks in (a).
when only the peaks representing the myoclonic jerks are present (Fig. XXV-13c), whereas it is more prominent if the peaks are partially eliminated (Fig. XXV-13d). These results suggest that the low-frequency component indicated in the autocorrelogram of Fig. XXV-13b represents a true tremor component, rather than an artefact of the analysis.

In Figs. XXV-15 through XXV-16 recordings and analyses are shown for another patient with the "cerebellar" type of tremor. From the ink-tracing of Fig. XXV-14 it is apparent that the tremor in this instance is not sustained at approximately the same amplitude as is the case in the tremor of Parkinson's disease (as has been shown in other figures) but rather it tends to be episodic or paroxysmal in nature; even during relatively quiet periods, however, there is considerably more motion than occurs with normal individuals, as will be apparent from subsequent figures. It is apparent from the crosscorrelogram that there is essentially no correlation between the tremor on the two sides. Furthermore, as is evident from the fact that successive oscillations in the autocorrelograms are essentially absent, the tremor on both sides, but especially on the left, is quite arhythmic in character.

For comparison of these results of accelerometric recordings from patients, findings from two normal control subjects are shown in Figs. XXV-16 through XXV-20. For these recordings, the same accelerometric sensitivity was used as that employed for Figs. XXV-11 through XXV-15. In Fig. XXV-16 portions of the ink tracings of recordings made while the upper extremities were held in the outstretched position are shown. In comparison with the recordings from patients, the tracings in Fig. XXV-16 are essentially flat, and no correlograms were computed from them.

Recordings of repetitive, synchronous movements of the type described above for Fig. XXV-16 (with the exception that the separation of the two points was approximately 15 cm instead of 20 cm) are shown in Figs. XXV-17 and XXV-18, for the two subjects respectively. In comparison with the results shown in Fig. XXV-15, several aspects of Figs. XXV-17 and 18 are readily apparent. First, the movement by the normal subjects
Fig. XXV-14. Recordings from a patient (C. G.) with bilateral intention tremor of the cerebellar type. Upper extremities in the outstretched position were unsupported.
Fig. XXV-15. Recording of repetitive, attempted synchronous movements by patient C.G. (indicated by the sharp upward spikes in the tracing). The attempted movement was that of touching alternately two points separated horizontally by approximately 20 cm, mirror images of the movement being attempted on the two sides.

Fig. XXV-16. Inked tracings of accelerometric recordings from the outstretched unsupported upper extremities for two normal subjects (B.J. and B.K.). The accelerometric sensitivity was the same as that for Figs. XXV-9 through XXV-15.
Fig. XXV-17. Recording from normal subject B.J. of bilaterally synchronous, mirror-image movements of the same type as those described in Fig. XXV-15.
Fig. XXV-18. Recording of the same type as in Fig. XXV-17 for a normal subject (B. K.).
is much more rhythmic, as evidenced by the fact that the second peak in the autocorrelogram was almost as high (0.75) as the first peak, in this rhythmic movement of a 1.4/sec repetition rate. Indeed a great precision of the basic repetition rate of the movement is indicated in the crosscorrelogram, which in this instance was computed for additional values of negative delay. Very little decrement is apparent between the second and third peaks to the left of zero delay in the crosscorrelogram. Also noteworthy in the crosscorrelogram is a crosscorrelation coefficient of 1.0; this indicates a quite exact synchrony of the movement on the two sides.

Quite similar results are apparent in the recordings from the second normal control, which are shown in Fig. XXV-18. Of further interest is the fact that the average repetition rate in the latter instance is not very different from that in Fig. XXV-17 (1.7/sec, and 1.4/sec, in Figs. XXV-18 and XXV-17, respectively). Similarly, synchronous and rhythmic movements were carried out by both normal controls upon accelerometric recording of the neurologist's standard finger-to-nose test, as evidenced from correlation analysis of recordings of the latter movement.

The very low-amplitude tremor that is present in Fig. XXV-16 for the accelerometric sensitivities used for that recording represents the so-called "physiological" tremor. Figures XXV-19 and XXV-20 represent additional recordings of the type shown in Fig. XXV-16, except that the accelerometric sensitivity has been increased by a factor of 10. Although the physiological tremor in Fig. XXV-19 is rather irregular, the presence in the autocorrelogram of peaks at 110 msec and another at ~400 msec is suggestive of components of an average frequency of 9.1/sec and 2.5/sec, respectively. Quite striking, from inspection of the crosscorrelogram, however, is the fact that only a suggestion of (crosscorrelation coefficient of 0.1) a correlation between the tremor on the two sides is evident.

For the control subject represented in Fig. XXV-20, there is also a suggestion of two principal frequency bands, the first centered at 8.3/sec, and the other at approximately 2/sec. A crosscorrelation coefficient of 0.25 suggests only a minimal relationship between the physiological tremor on the two sides. The low value of the crosscorrelation coefficient for both of these normal controls contrasts strikingly with the similarity of the autocorrelograms (especially those shown in Fig. XXV-20) for the tremors on the two sides.

From the results described here, it is apparent that correlation analysis of accelerometric recordings of movement phenomena, in both the normal and diseased states, provides a convenient and valuable method for investigation between motor phenomena in the two upper limbs. The ease with which the accelerometers can be applied to the limbs, and the complete freedom of motion that they permit, are especially advantageous.

Analyses of recordings from patients with tremor of the Parkinson type suggest the presence of common components in the tremors from the two sides even though, as
Fig. XXV-19. Recordings of the same type as in Fig. XXV-16, but with accelerometric sensitivity increased by a factor of 10, to show the "physiological" tremor. (Subject B.J.)

Fig. XXV-20. Same conditions as in Fig. XXV-19 for subject B.K.
determined by autocorrelation analysis, the average frequencies of the predominant tremor activity on the two sides are slightly different.

It should be remembered that the autocorrelogram yields the average period (and hence rate) of the tremor for the duration of the recordings (in the present instances, 4 minutes), and hence moment-to-moment changes in tremor rate are reflected only intrinsically (i.e., in the manner of decrement, with increasing delay, of the amplitude of the envelope of the autocorrelogram) rather than extrinsically. It is conceivable, therefore, that the common component that is apparent in the crosscorrelogram represents primarily those intervals of time of the recording during which the tremor rates on the two sides are identical. That the appearance of the common component in the crosscorrelogram is not due solely to sampling artefact is quite clear from the cross-correlation of tremors from patients with simulated tremors recorded simultaneously from normal controls (Figs. XXV-7 and XXV-9).

The possibility that the common components appearing in the crosscorrelograms for bilateral tremors may arise at least in part from mechanical crosscoupeling between the two sides must be considered as an alternative to physiological origin (i.e., a common "driving frequency" for the two), and additional recordings from normal subjects will be required in order to examine this possibility more fully. For this purpose, simulated tremors of slightly different rates on the two sides could be crosscorrelated. Several of the present results, however, mitigate against this possibility as a major source of the common component in the crosscorrelograms. In Fig. XXV-10, for example, the tremor rate of 1.5/sec that is apparent in the crosscorrelogram reflects the presence of this component on the left side, and to a much lesser degree on the right side, as evidenced by the autocorrelogram for the latter. The very prominent tremor of an average rate of 5/sec on the right side, however, is not reflected at all in the autocorrelogram. Accordingly, if the 1.5/sec component in the crosscorrelogram were due entirely to mechanical crosscoupeling, then the 5/sec component could also be expected to be present. The latter is, however, not present in the crosscorrelogram. Additional evidence against the possibility of mechanical crosscoupeling as the prime source of common components in the crosscorrelogram is the absence of such a component in the crosscorrelogram of Fig. XXV-15.

The present results provide some quantitative evidence for support of the observation by Dr. Schwab that the bilateral tremors of Parkinson's type manifest a tendency toward synchrony, whereas those of the cerebellar type tend to be asynchronous on the two sides. At the same time, it is evident from these findings that the average tremor rates on the two sides in Parkinson's disease may not be identical, even though common components do appear in the crosscorrelogram. Moreover, common components may appear in the crosscorrelograms for bilateral tremors of the cerebellar type in some instances, even though the average tremor rates may be quite different on the two sides.
Furthermore, with suitable posturing and support of the limbs, quite similar cerebellar tremors may appear on the two sides (Figs. XXV-11 and XXV-12). This is not the case, however, if the movement disorder on the two sides is markedly arhythmic and asynchronous (Figs. XXV-14 and XXV-15). It may be, therefore, that it is in patients with the latter type of movement disorder that the stabilization of the upper limbs afforded by the clasping of the one by the other is the most effective. That this maneuver should also be effective against the normal or physiological tremor can be inferred from the very minimal crosscorrelation of the latter (Figs. XXV-19 and XXV-20).

The fact that the rate of physiological tremors lies within the alpha-frequency range of the human EEG (8-13/sec) has long been of interest, and the question of whether there is a relationship between physiological tremor and cortical rhythmic activity has naturally arisen. Studies of tracings of simultaneous recordings of the two, however, have not yielded positive results. On the other hand, the great potentiality of crosscorrelation for detecting common but (in the inked trace) hidden components suggests that this problem be re-explored with the aid of correlation techniques.

Further recordings from additional patients with different types of tremors, as well as from normal subjects, and with additional types of controls for artefacts, are planned for more extensive exploration of these questions.

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