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ABDOMINAL SURFACE POTENTIALS AND
THEIR RELATION TO GASTRIC MOTILITY

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**ABDOMINAL SURFACE POTENTIALS AND
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Roger W. Russell, Project Director

PREFACE

During several years of operations under Contract Nonr 908, our laboratory has concentrated its effort on the empirical study and theoretical analysis of relations between behavior and electrophysiological variables of the kind which R. C. Davis, the original Project Director, referred to as "somatic responses." As Davis pointed out:

"... somatic responses abound. One has but to observe them on a set of measuring instruments to believe that they are by far the most numerous responses of the organism. It is clear that any overt response, vocal utterance, or bodily movement, is surrounded by a wide penumbra of them, and it may not be too bold a guess to say that whenever there is any evidence of a stimulus affecting the individual, something in his periphery or viscera is set into motion."

These are responses which can be recorded from electrodes placed at various locations on the surface of the body.

Developments in contemporary biological sciences and their related technologies are making abundantly clear the view that knowledge about interactions among all properties -- anatomical, behavioral, biochemical and electrophysiological -- is essential to understanding the nature of living organisms. Research under Contract Nonr 908 has been oriented around relations between behavior and the electrophysiological activities of various tissues and organ systems as recorded from electrodes on the surface of the body; under their normal operating conditions and when the biochemical

characteristics of these conditions have been altered experimentally using drugs as tools. Results of the research indicate that somatic responses may be related to behavior in three basic ways: (1) they may serve as stimuli, preceding and affecting subsequent responses; (2) they may accompany responses to other types of stimulation; and (3) they may be the only objectively observable consequences of stimulation, when overt changes in behavior do not appear.

In the series of experiments of which those reported here are a part we have directed our attention to somatic responses originating in the gastrointestinal tract. It is estimated that more of man's time and effort are devoted to the satisfaction of his needs and appetites for food and drink than to any other form of human behavior. The thousands of biochemical events involved in keeping him alive and in supporting his activities are dependent upon the input of chemical substances which are normally absorbed through the walls of the g.i. tract after having been pretreated in the special chemical and physical environments which exist in the lumina of different sections of the tract. Deprivation of food or drink increases the level of man's general activity, and the presence of food and water serves to reinforce the learning and maintenance of a multitude of behavior patterns. His general relation between behavior and g.i. activity is reciprocal in the sense that exposure to psychological stresses may produce significant danger in the g.i. tract, as evidenced, for example, in the ulcerous disorders of psychosomatic origin. An understanding of the functioning of the g.i. tract in health and illness is obviously a matter of very considerable importance.

We believe that the research reported in the pages to follow constitute an important advance in our series of studies by (1) providing additional evidence that the electrogastrogram (EGG) is a valid and reliable measure of gastric activity and (2) laying the ground-work of a fuller and more sophisticated approach to the analysis of somatic responses as we record them. The new approach is now being applied in experiments on infrahuman arrival subjects exposed to chronic stress and in clinical studies of human patients suffering from a variety of g.i. disorders. We believe that this research has promise not only of adding to knowledge about interactions between behavior and the somatic responses involved, but also of providing technological advances of value to the diagnosis and treatment of g.i. disorders.

Roger W. Russell
Project Director

ABDOMINAL SURFACE POTENTIALS AND
THEIR RELATION TO GASTRIC MOTILITY¹

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Research on the functioning of the gastrointestinal tract has employed a variety of methods for recording and analyzing gastric motility. Most of the methods, i.e., recording intragastric pressure, fluoroscopy, electromagnetic and telemetering techniques, require placement of a recording device or one of its components in the stomach and thus involve the risk of producing artifacts in normal activity by direct stimulation of receptors in the stomach wall. The possibility that the dynamics of gastric motility might be studied in terms of changes in bioelectric potentials generated by the stomach and detected at a distance from their source was recognized by Alvarez in a 1922 report (1) "The Electrogastragram and What It Shows". From electrodes positioned on the skin surface of the abdomen over the stomach Alvarez recorded a predominant activity at three deflections per minute. With the development of more sophisticated apparatus for amplifying bioelectric potentials Soviet workers turned their attention to applications of the method and now have it in experimental clinical use for detection of gastric disorders (14, 15, 16).

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During the period between the Alvarez report and today's clinical applications, research effort has been directed toward three basic methodological issues: standardizing the recording techniques for the EGG, refining the methods of analyzing the records obtained, and establishing the validity of the EGG as an accurate and reliable measure of gastric motility (8, 9, 19). The studies reported below were designed to provide further information relevant to the second and third of these issues. Significant relations were found between mechanical activity, as recorded from force transducers located directly on the surface of the stomach, and electrical activity recorded by the Davis (8, 9) technique. For experimental purposes, gastric motility was varied pharmacologically and by mechanical distention of the stomach. The recordings also provided material for demonstrating the computerized method of pattern recognition, i.e., autocorrelation, crosscorrelation, and Fourier analysis, as a more adequate and less laborious approach to the quantitative analysis of its major parameters. In addition, the experimental data served as a basis upon which to develop a model of the mechanisms underlying the EGG.

METHOD

Seventeen cats were used in preliminary studies to test the adequacy of surgical and recording techniques. Four additional animals, females ranging in weight from 2.2 to 3.3 kg. were used to obtain the recordings analyzed below. All animals were given a period of isolation upon entry into the laboratory, during which they were wormed, distempered and examined for general condition of health. All were maintained on a high-grade ad-libitum diet throughout the experimental period.

Mechanogram.--The present experiments used in vivo, extraluminal, contractile force transducers similar to those described by Jacoby, Bass and Bennett (13). Baldwin-Lima-Hamilton type SR-4, PEA-25-12 post yield strain gages constituted the basic transducer unit. Polyethylene coated no. 32, stranded wire leads were soldered to each terminal and the unit's surface coated on both sides with Dow Corning 732 RTV Silastic. The unit was sandwiched between two 1 x .05 x .02 cm Medical Grade, Dow Corning Silastic sheets.³ Each transducer was allowed to cure for 24 hrs. and then tested electrically for its general reliability. Finally, two Amphenol type 220-804-2 female gold contacts were soldered to the free ends of the wire leads for later attachment to a connector mounted on the skull.

Standard surgical procedures were used to attach the transducer units to the stomach. Cats were deprived of food for 24 hrs. prior to administration of pentobarbital anesthesia at dose levels of 38 mg/kg body weight. An incision was made 1-2 cm caudal to the xiphoid process and the abdominal wall spread to expose the stomach. The sterilized transducer unit was sutured through the peripheral edges of its Silastic cover to the upper two smooth muscle layers at a site in the lower body of the stomach. Leads were passed subdermally to a small dorsal incision in the skin over the skull and inserted into a type 233, 5-contact Amphenol Micro-Med connector. The full assembly, which also contained a mounting for the cannula described below, was attached to the skull with dental cement. During recording sessions the force transducers were coupled to a DC type R Offner Dynograph through a strain gage bridge circuit (21) powered by a 6 v. wet-cell battery. The

³Provided by courtesy of the Dow Corning Center for Aid to Medical Research, Midland, Michigan, 48641.

location of the transducer unit was later verified by X-ray photography⁴ as illustrated in Fig. 1. No obvious tissue reactions were apparent upon autopsy. In one case, histological examination showed that smooth muscle had overgrown the entire transducer unit.

Electrogastrogram.--Two types of electrodes were used in recording the EGG: Grass EGG silver-silver chloride and E. M. I. type suction electrodes. There was no perceptible difference in quality of tracings from the two types. Offner type electrode paste was used for both types. The standard position for the active electrode was 2 cm caudal to the xiphoid process, but a second active electrode was used during many sessions to explore other locations on the abdomen. The reference electrode was always positioned on the skin over the inner left femoral muscle. The electrodes were directly coupled to a DC type R Offner Dynograph using a low pass filter with a time constant of 2.5 sec. to eliminate EKG artifacts.

Procedure.--Cats were food deprived for 24 hrs. prior to all recording sessions. All animals were allowed to satiate themselves on a standard meal of either cheese or raw beef before intraventricular injection of the sedative in order to insure strong peristaltic activity during recording. No food was given before sessions during which effects of mechanical distension of the stomach were studied.

1.0 to 2.5 mg. chloralose in .5 cc. normal saline was injected intraventricularly via a cannula. The effective sedative dose varied from animal to animal and was determined individually. Intraventricular administration seemed to keep peripheral effects of the sedative to a minimum. Gastric motility as measured via the force transducer, was depressed only during the

⁴Courtesy of the Indiana University Student Health Center.

first 30 mins. after injection of chloralose, while the sedative effects of the drug remained up to 4 hrs.

Once relaxed, the cat was laid supine in a shielded cage. The abdominal skin area was shaved, cleaned with alcohol, and the EGG electrodes attached as described earlier. Recording began within 5 mins. after the electrodes were attached and continued until effects of the sedative had disappeared to the extent that the animal's movements produced artifacts in the tracings, a period of from 1 to 4 hrs.

For the drug sessions, either physostigmine (.2 mg) or Probanthine (15 mg) was injected through the intraperitoneal route. For sessions involving mechanical distension, a catheter was inserted into the cat's esophagus, air injected at a fast rate, and then allowed to escape at a slower rate. Simultaneous records of the EGG and the mechanogram were taken.

Intraventricular administration of sedative.--In order to minimize peripheral effects of sedatives given to immobilize the animals during recordings of EGG's and mechanograms, the intraventricular route of administration was used. As a final step in the general surgical procedure described above for attaching the transducer units for the mechanogram, the cat was placed in a Horsley-Clarke stereotaxic unit and a Feldberg-type cannula (11) implanted in the right lateral ventricle. Its location was verified by observation of cerebrospinal fluid in its lumen.

Analysis of records.--Two methods were used in the analysis of records, samples of which are shown in Fig. 1. In the conventional analysis (8, 9) tracings were visually inspected for areas with a minimum number of movement artifacts and resets due to drift in the EGG. In the case of the slower waves, frequency was estimated by measuring the time in seconds for the occurrence of 10 successive waves and the rate per minute was obtained by

dividing this value into 60 min. x 10 waves. Frequency for faster activity superimposed upon this base was determined by counting the number of waves which occurred in the same time interval, and converted to a rate value as above. This was finally repeated for the corresponding mechanogram.

The second method was undertaken for illustrative purposes. It involved the use of techniques which have long been used in the field of communication theory (23) and have recently been applied to biological systems as a means of identifying basic patterns in bioelectric data (10). The analog data, recorded on standard Offner curvilinear paper, were digitized by hand at one second intervals for a fifteen minute sample; this procedure has since been eliminated by automatic analog-digital conversion.

The technique of autocorrelation, as described in detail by Rosenblith (18), was then applied to the digitized data using 150, one second, lag points; this provided the information needed to plot the correlograms. The next step was to fit the correlograms with Fourier series, thus giving relative power values for each of their frequency components which could be plotted as "power spectra". Crosscorrelations were also computed as a means of determining relations between pairs of electrical and of mechanical and electrical tracings from the same cat. This technique (18) is analogous to autocorrelation except that the values of the correlogram are determined from two rather than one time series and each record shifted over only 75 lags from the zero lag point. These analyses made it possible to identify periodicities common to each pair of time series and, in addition, to identify phase differences between records in each pair, expressed as the distance of maximum correlation from the zero lag point (Fig. 4). Fourier series were also fitted to produce power spectra of components common to various pairs of the records. The analysis described above were carried out using

the UCLA Biomedical Program, H4DO2T⁵.

RESULTS

Correlations between EGG and Mechanogram.--Results of the conventional analysis are summarized in Table 1. The statistics reported are based upon samples of 140, 340, and 100 slow waves for cats I, II, and III, respectively; a second independent sample of 140 waves was taken simultaneously and analyzed for cat I's records. The slow wave component of both the EGGs and mechanograms were in the range of approximately 3.5 to 5.5 waves per min., while the faster waves in the EGGs varied from about 9 to 25 waves per min. The high degree of correspondence between the two types of measures is most apparent in the very significant ($< .005$) coefficients of correlation. Test of the differences between measures of electrical and mechanical activity were all significant at a level less than .005. This is most likely due to the phase shift between the EGG and mechanogram which in turn biased the number of mechanogram waves counted in any given EGG, 10 wave segment.

Pattern recognition.--Three mins. of the 15 min. recording analyzed with the computer is shown in Fig. 1. The upper EGG, "a", was obtained with the active recording electrode in the position indicated in Fig. 1; EGG, "b", was recorded simultaneously from the position indicated in the same x-ray photograph. The location of the transducer, which provided mechanograms over the same time period is shown as "m" in the figure. Visual inspection suggests that each of the EGGs constitutes a complex biphasic time series, while the mechanogram has a relatively simple sinusoidal form. By conventional analysis

⁵Developed by the Health Sciences Computing Facility, Department of Preventive Medicine and Public Health, School of Medicine, University of California, Los Angeles, California.

TABLE 1: RESULTS OF CONVENTIONAL ANALYSIS

	I	Cat number II	III
A. Slow Waves			
1. Mechanogram			
Mean (cycle/min.)	4.18	4.51	4.54
Standard Deviation	.28	.81	.92
2. EGG (Sample 1)			
Mean (cycle/min.)	4.51	4.33	3.76
Standard Deviation	.73	.92	.69
3. EGG (Sample 2)			
Mean (cycle/min.)	4.51	—	—
Standard Deviation	.98	—	—
4. Coefficients of Correlation			
EGG 1 and Mechanogram	.84	.86	.85
EGG 2 and Mechanogram	.78	—	—
B. Fast Waves			
1. Mechanogram			
	0.00	0.00	0.00
2. EGG			
Mean (cycle/min.)	12.89	11.16	16.51
Standard Deviation	2.68	1.18	5.30

Summary of statistical analysis of hand read data. Slow wave sample size was 140, 340, and 100 waves for cats I, II, and III respectively. The large mean difference between the EGG and mechanogram of cat III is most likely due to the small sample size, phase shifts, and errors inherent in hand record reading, however all coefficients of correlation were significant at a confidence level less than .005. It should also be noted that only one simultaneous EGG was taken for cats II and III, while two were taken for cat I. Fast wave analysis includes all of the fast waves in the EGG samples used for slow wave analysis. No significant fast wave component appeared in the mechanogram.

tracing "a" has a base frequency of 4.1 cycle/min., with a faster, 11-12 cycle/min., component superimposed; the slower frequency is not as obvious in "b" and the faster component appears reduced in amplitude. The 4.1 cycle/min. wave completely dominates the mechanogram, "m" and looks to be out of phase with its corresponding component in "a".

When autocorrelation was applied to the sample record the overall complexities of the EGG tracings were markedly reduced, as shown by the plots in Fig. 2. Since Gaussian random noise is transformed to exponential form and appears as the slope of the composite curve between zero and the 150th lag point, there is evidence that random noise was greater in tracing "b" than in tracing "a", while the mechanogram, tracing "m", is almost noise-free. With the data in this form, periodicities are much easier to identify and relations between tracings more readily apparent.

The fitting of a Fourier series to the data makes it possible to determine the relative frequencies with which the basic periodicities occurred in each sample of record. Figure 3 shows that in the two EGG tracings, the most prominent peaks occurred at four major frequencies: 4.2, 9.4, 11.8, and 18.6 cycle/min.

Crosscorrelations, computed for each pair of the sample records, are plotted in Fig. 4. The plots make it possible to identify periodicities common between pairs of records, the high degree of correspondence between the mechanogram and each of the EGGs being particularly striking. The occurrence of a peak at the zero lag point in the correlogram for records "a" and "b" indicates that there was no detectable phase shift between the two EGG tracings. In view of the fact that the two recording electrodes were located more than 4 cm apart, this observation will deserve special attention in interpreting the results. Figure 4 shows clear phase differences in the

correlograms for the mechanical and electrical recordings; shifts between the peak and zero lag points corresponding to differences of 50° .

Fourier analysis provided data for relative power spectra plotted in Fig. 5. The power spectrum, Fig. 5A, between the two EGGs shows major peaks at the same four frequencies as those in the autocorrelation analysis (Fig. 3): 4.2, 9.4, 11.8, and 18.6 cycle/min. In the relations between the EGGs and the mechanogram the peak at 4.2 cycle/min. is much more prominent in comparison with peaks at other frequencies.

Effects of drugs and mechanical stimulation.--The evidence presented above clearly supports the proposition that the EGG as a tracing of bioelectric potentials which are closely correlated with gastric activity recorded by direct mechanical coupling. Further evidence of such a relation would come from observations of simultaneous electrical and mechanical recordings under conditions in which gastric activity was varied experimentally, i.e., by drug and mechanical stimulation. The tracings in Fig. 6 illustrate the close concomitant variation of the two under such conditions.

The tracings in Fig. 6A were controls recorded 5 min. prior to drug administration; they show the characteristic periodic activities, both in the EGG and mechanogram, described earlier. Figure 6B is a sample of the record 10 min. after .2 mg physostigmine, an anticholinesterase, was injected ip. As in the results of in vitro studies (12, 20) would predict, strong tonic contractions occurred concomitantly in both tracings. Separate records of breathing had the same frequency as the faster components in the mechanogram, suggesting that the latter probably arose from respiratory activity.

Figure 6C is the control tracing prior to ip injection of 15 mg of Probanthine. Both electrical and mechanical records have a common slow wave component. Initially the injection seemed to facilitate electrical activity,

as indicated in Fig. 6D and to cause the occurrence of arrhythmia in the mechanical record. Eight mins. later, as shown in Fig. 6E, the slow components in both the mechanogram and the EGG were completely suppressed, leaving only the faster components.

Effects of mechanically stretching the stomach by blowing air into the gastric lumen via an esophageal catheter are shown in Fig. 6F. Again the tracings are seen to vary concomitantly in a highly correlated manner, all components appearing to be affected. The x-ray of this particular cat indicated that an intestinal segment was in proximity to the force transducer leading to the fast periodic activity found in both the EGG and mechanogram.

DISCUSSION

Validity of the EGG.--Results of the present experiments clearly provide support for the validity of the EGG as an accurate and reliable measure of gastric activity. Conventional analysis of the EGGs and the mechanograms showed a dominant activity for all cats in the range, 3.5 to 5.5 waves per min., with high correlations between the two types of recording. This relation appeared with even greater clarity when the EGGs and mechanograms were subjected to the more sophisticated analysis of crosscorrelation and the latter fitted with Fourier series. These results are also consistent with reports of experiments involving recordings from electrodes placed directly on the surface of the stomach; for example, Daniel and Chapman (6) have described activity in the range of 3 to 6 waves per min. with electrodes on the antrum of the dog. Taken together these and other (19) sources of evidence support the assertion that the EGG, although recorded at a distance from the source, registers the tissue changes which constitute gastric activity.

It is apparent in Table 1 and in the power spectra in Fig. 3 that the EGG as recorded by the Davis' method also registers other rhythmic activity. This is in contrast to the mechanogram which normally had but one dominant peak frequency. Peaks in the EGG at 11.8 and 18.6 waves per min. approximated the ranges of frequencies recorded by others (6, 17) with electrodes placed directly on the ileum and the duodenum, respectively, suggesting the possible sources of the two components.

Mechanisms of actions.--Results also suggest certain mechanisms of action which may underlie the EGG. The results of recent investigations (2, 3) suggest that the slow DC potential present in the longitudinal smooth muscle may act as a pacemaker, without directly initiating depolarization and, hence, mechanical contraction. Tami and Prosser (22) demonstrated that this contraction could arise from two possible mechanisms: (a) increase in amplitude of these slow DC potentials due to metabolic fluctuation at near threshold levels, (b) electrical driving of slow-waves to firing level. They also noted that a critical slow-wave amplitude of approximately 5 mv is required to initiate a contraction. Generally, slow waves below this critical level did not bear spikes, whereas those above it did have depolarization spikes. This suggests that contraction is a function of electrical activity, but since the triggering threshold is critical, only a slight increase in the amplitude of the slow wave would be sufficient to initiate a contraction. Consequently, a small increase in amplitude of the electrical record should often be accompanied by much larger contractile activity. Unfortunately, the extreme complexity of the EGG prevented us from obtaining any reliable indicator of the amplitude of a specific wave form, but the relative independence of the two parameters' amplitudes can be seen in Fig. 6.

It may also follow from this reasoning that a small decrease in amplitude of the electrical wave should cause a large decrease in the mechanical contractions. Assuming that a contractile wave exists due to the slow-wave's being electrically driven from cholinergic nerve endings, Tami and Prosser's hypothesis would predict that a cholinolytic drug would decrease the amplitude of the electrical slow-wave and disproportionately suppress the stomach's mechanical contractions. When 15 mg Probanthine was injected (Figs. 6C, 6D, and 6E), this prediction was not initially confirmed, and arrhythmia in the mechanogram along with slow contractions in the EGG (Fig. 6D) seemed to be the immediate effect. This could have been due to a localized vasoconstrictor effect of Probanthine. Eight mins. later, however, the slow $\frac{1}{4}$ cycle/min. wave form did show the expected decrease while no mechanical activity in this frequency range was present. Physostigmine is known to increase overall tension in smooth muscle due to its inhibition of cholinesterases (12, 20). This leads to the hypothesis that the same mechanisms as those involved in the action of Probanthine, but in the reverse, were responsible for the effects produced by this drug, i.e., the slow wave was driven to above threshold levels leading to strong mechanical contractions (Figs. 6A and 6B).

Mechanical distension was a more direct means of stimulating the gastric musculature. It is known that stretch or an increase in tension produces a maintained depolarization (5). Since in this situation the mechanical change preceded any electrical changes, no critical threshold levels were needed to produce mechanical activity. This view is supported by Bulring (4), who has demonstrated that changes in membrane potential are a direct function of changes in tension and is also confirmed in our distension experiments (Fig. 6F).

Model of the EGG.--There is one additional empirical observation which

deserves particular attention: simultaneous recording from two active surface electrodes produced tracings which were in phase (Fig. 4A), regardless of their placements on the abdomen. A model of the EGG must take this, as well as other properties into account.

The construction of such a model can begin with the fact that, when electrical activity is recorded from electrodes placed directly on the gastric wall, a decrement can be observed in propagation rate over the surface of the stomach, from .5 cm/sec. in the fundic region to approximately 4 cm/sec. in the lower antrum (6). It may then be argued that the faster the conduction rate, the greater the number of muscle cells depolarized at any given time. In other words, maximum contribution of the surface potential will come from those muscle segments which have the highest conduction rate. This is illustrated in Fig. 7. At $T = 0$, the wave of contraction is in a slow conduction region. Three seconds later ($T = 3$) the wave has been propagated into a region of high conduction rate. In Fig. 7 the area between threshold and peak of the wave is proportional to the number of cells depolarized. The larger the area over which the wave is propagated, the greater its contribution to the EGG electrode. This would suggest that the 4 cycle/min. component is primarily a consequence of antral-pyloric electrical activity, since conduction is greatest there. Moreover, according to this model phase shifts would be kept to a minimum no matter what the electrode location. This effect has been demonstrated with a mathematical model, but due to lack of accurate data regarding conduction rates, the absolute phase shifts as a function of electrode position have not yet been computed.

Another implication of the model illustrated in Fig. 7 is that the most effective electrode position for recording the EGG would be directly over the antrum, as was the case in the present experiments (Fig. 1). Soviet workers

have had difficulty in obtaining high correlations between electrical activity recorded on the abdominal surface and recording of changes in intragastric pressure using large balloons, whereas smaller balloons located in the antral region did yield high correlations (15). The model suggested above would predict this. Furthermore, it is known that contractions do increase in strength upon approaching the antral region (7), a fact also predicted by the model.

Methods of analysis.--The application of autocorrelation and Fourier analysis have been shown to yield information unattainable by the conventional method of analysis, but certain disadvantages should be noted. First, because of the averaging process it entails, the method can be used only for the general description of the EGG and not for changes which occur within a record. Analysis of shorter time segments would reduce this problem, but never completely; the problem also arises that, as the sample is shortened, the theoretical assumption of an infinite time series is violated to an increasingly greater extent. Secondly, data must be converted to digital form which unless analog-to-digital equipment is available is extremely tedious. Thirdly, the method of autocorrelation assumes that the data being analyzed is periodic and represents a stationary, stochastic time series. Farrar (10) has found the method to be unreliable for analysis of records obtained by intragastric balloon technique and has pointed out that such data does not satisfy the above assumptions. However, the biphasic EGG and mechanogram tracings recorded in the present experiments, although not completely stationary and periodic, approximate these assumptions so closely as to provide the consistent results reported earlier.

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FIGURE CAPTIONS

Fig. 1

A typical 3 min. portion of the 15 min. record used for computer analysis with the x-ray photograph of the cat (in supine position) from which the record was taken. The small rectangle, "m", indicates the location of the force transducer; "b" is the electrode position for record "b" and "a" is the electrode position for record "a". Reference electrode was positioned over the inside left femoral muscle.

Fig. 2

Autocorrelations of the records represented in Fig. 1. The ordinate is a normalized relative scale, and has no real meaning other than for comparison between correlograms. The abscissa represents the time lag from 0 to 150 sec. in increments of 5 sec. The autocorrelations of records "a", "b" and "m" in Fig. 1 are shown in "A", "B", and "C" respectively.

Fig. 3

Power spectra of autocorrelations shown in Fig. 2. Ordinate is an arbitrary log power value. Abscissa is frequency in 1.02 cycle/min. divisions. "A", "B", and "C" are power spectra of autocorrelations "A", "B", and "C" in Fig. 2 respectively.

Fig. 4

Crosscorrelations of records in Fig. 1. Ordinate is a normalized relative scale as in autocorrelations, and the abscissa is time lag ± 75 sec. "A", "B", and "C" are the crosscorrelations of records "a", and "b", "a" and "m", and "b" and "m", respectively. If two records are in phase a peak will occur at the zero lag point as in "A". Similarly, two records out of phase, as indicated in "B" and "C", will have a corresponding phase shift from the zero lag.

Fig. 5

Power spectra of crosscorrelations in Fig. 4. The ordinate is an arbitrary log power scale and the abscissa is frequency in 1.02 cycle/min. increments. "A", "B", and "C" are power spectra of crosscorrelations "A", "B", and "C" in Fig. 4.

Fig. 6

Records of drug experiments. The upper record is electrical and the lower is the mechanogram. Time mark is 30 sec. and voltage bar is 2 mv. "A" is control record five min. prior to physostigmine. "B" is two min. after injection of .2 mg of physostigmine intraperitoneally. "C" is control record for Probanthine, "D" is two min. after injection of 15 mg. Probanthine intraperitoneally and "E" is 8 min. later. "F" is effect of air injection into the lumen as indicated. Apparent phase shift is due to the fact that the record was taken on curvilinear paper.

Fig. 7

Model demonstrating effects of propagation rate decrement. Upper graph at $T = 0$ represents electrical wave at the start of contraction. Diagram is the mechanical contractile wave produced by the electrical wave in a 7 cm segment of smooth muscle. Lower graph and diagram is the same system ($T = 3$) 3 seconds later.

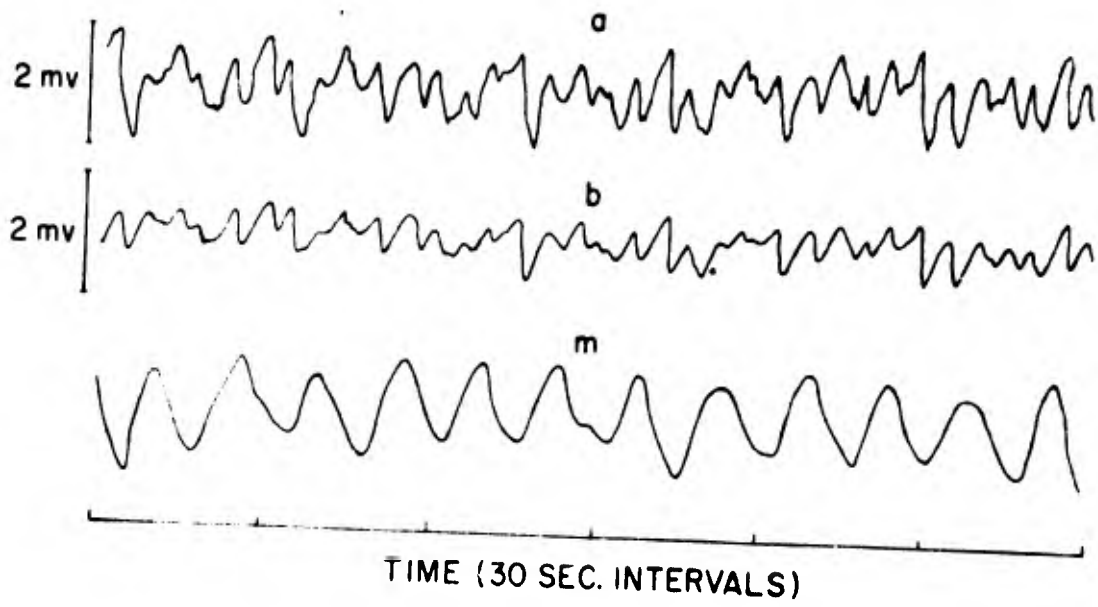
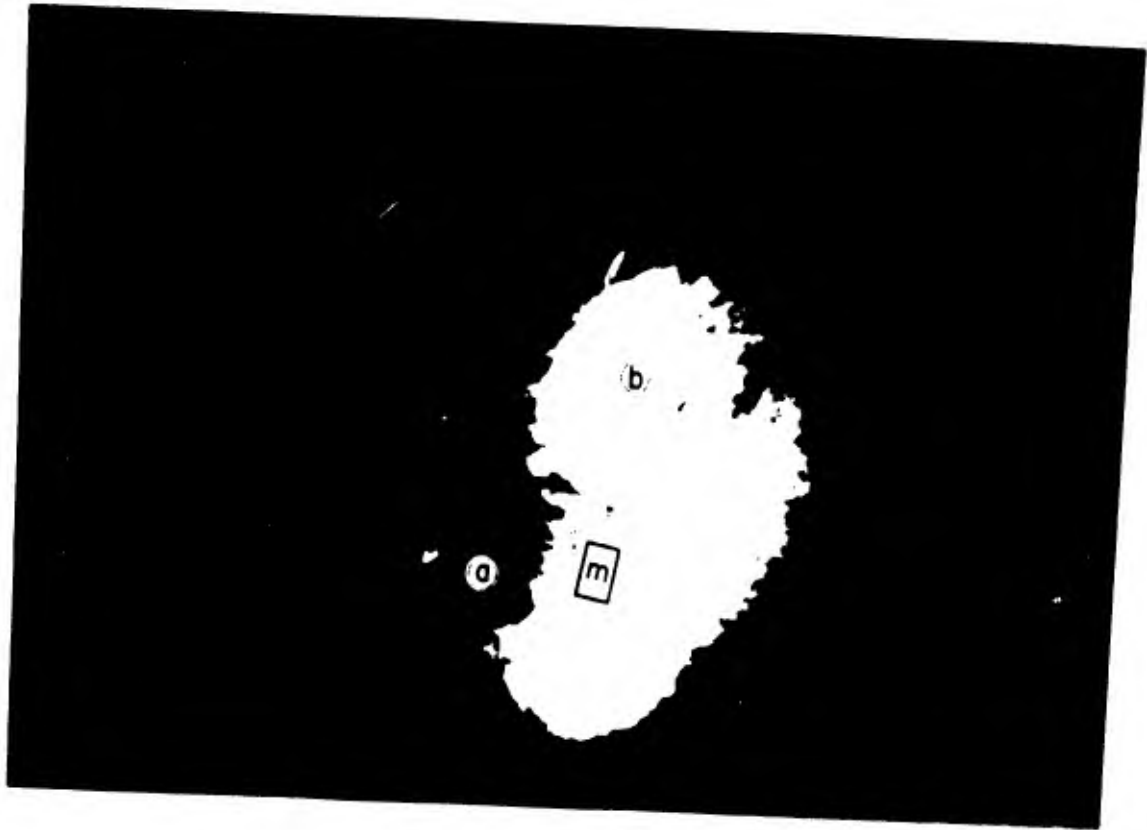


Figure 1

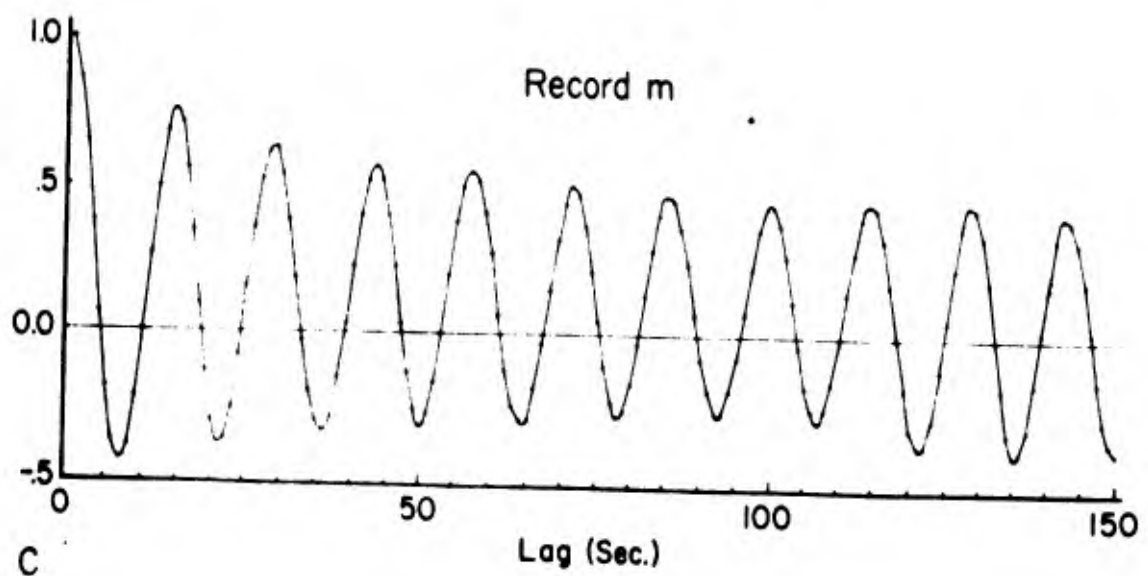
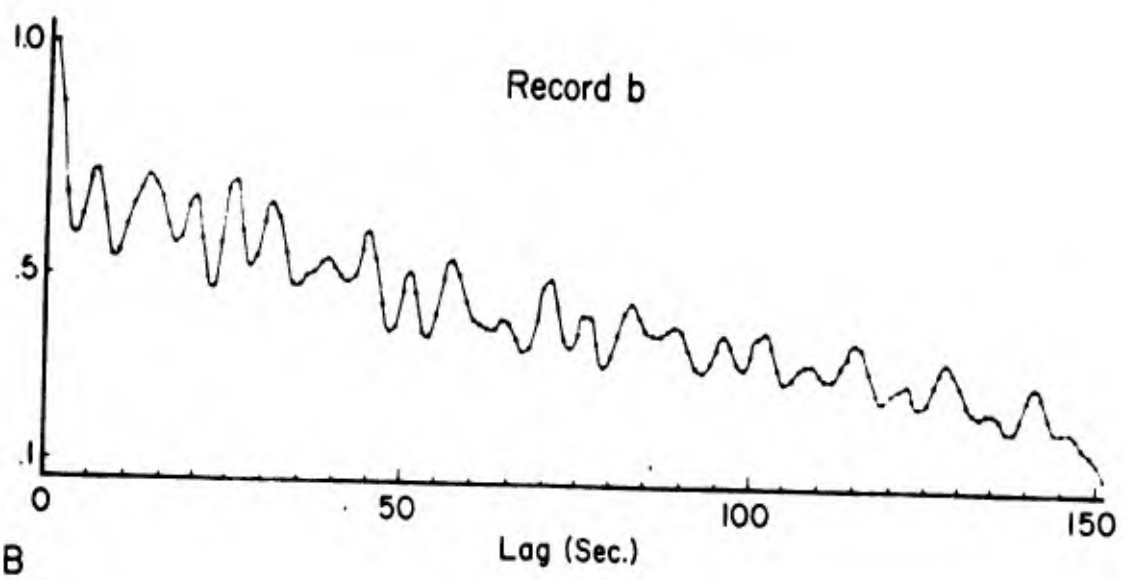
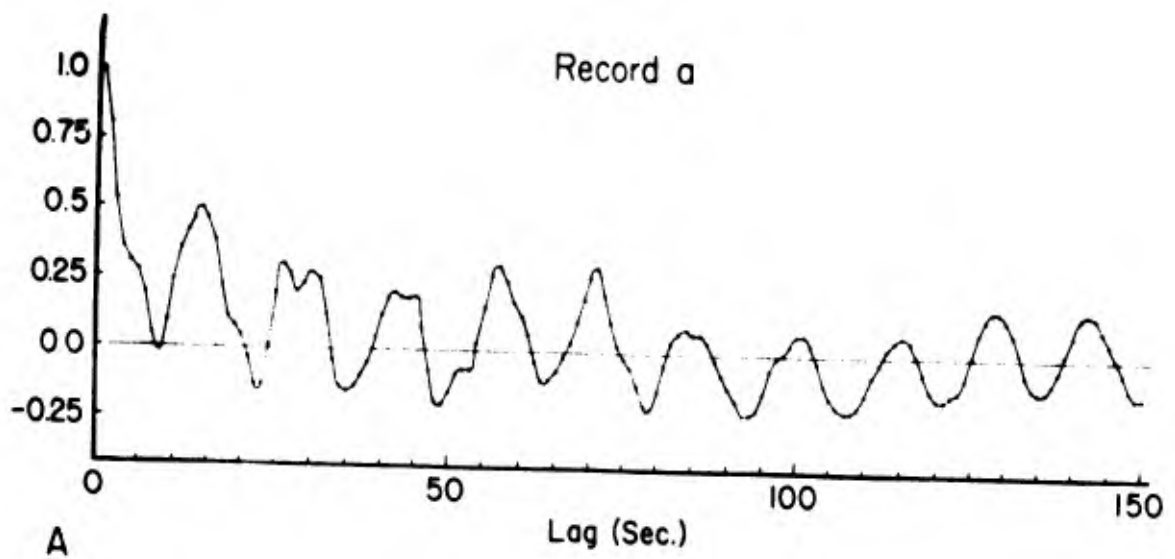


Figure 2

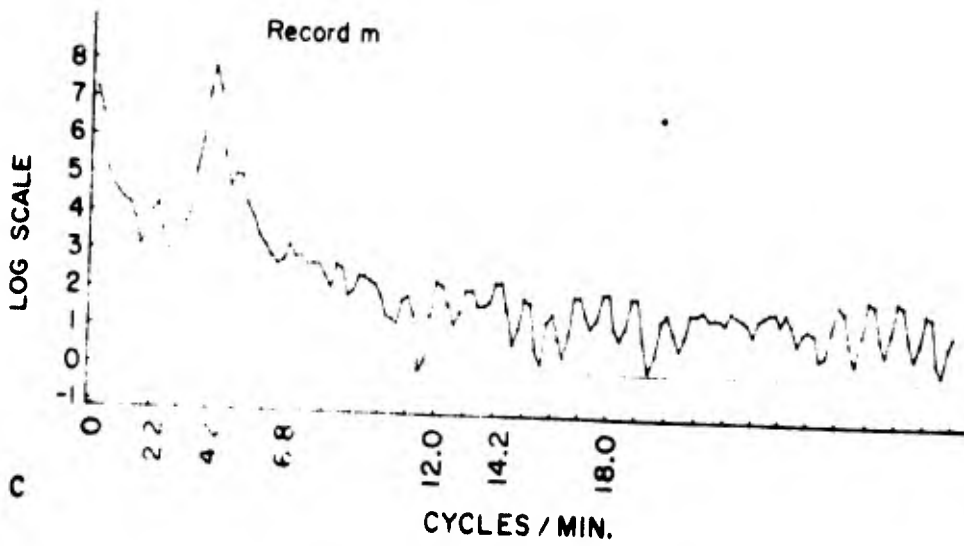
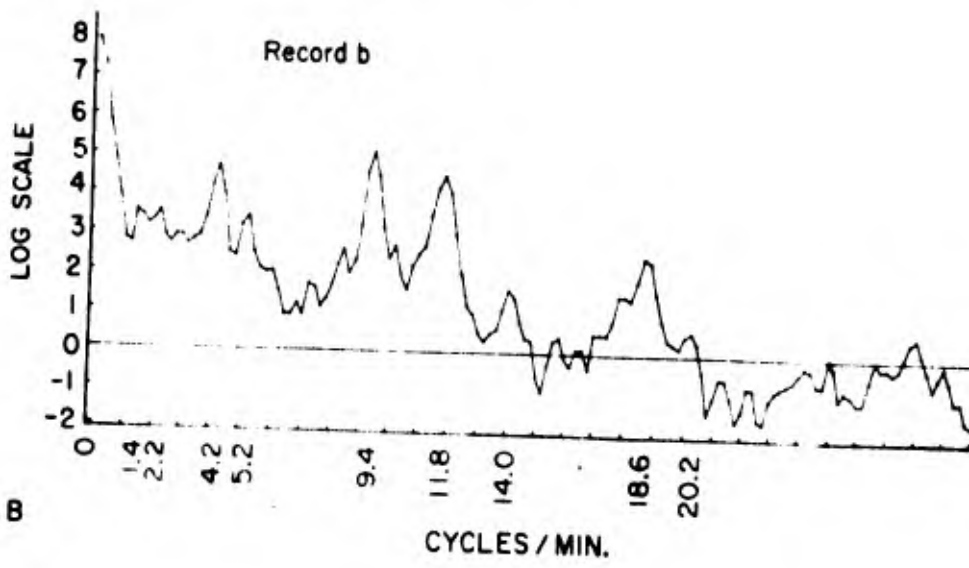
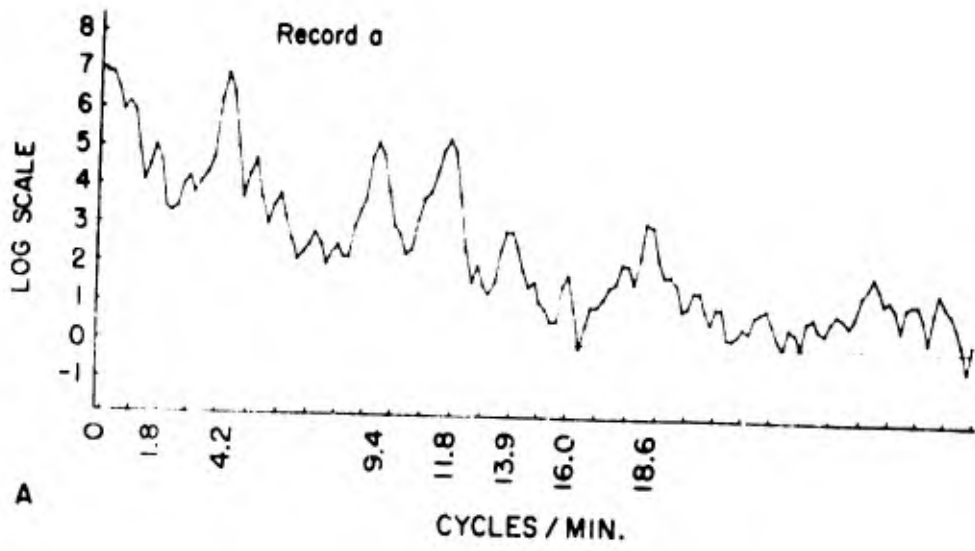
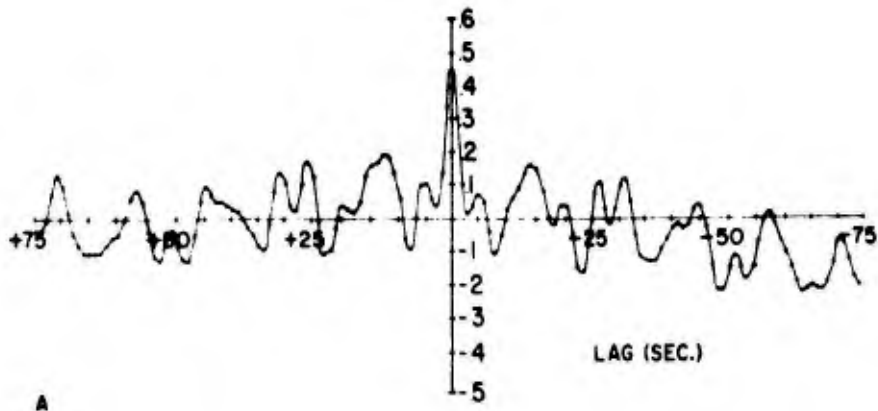
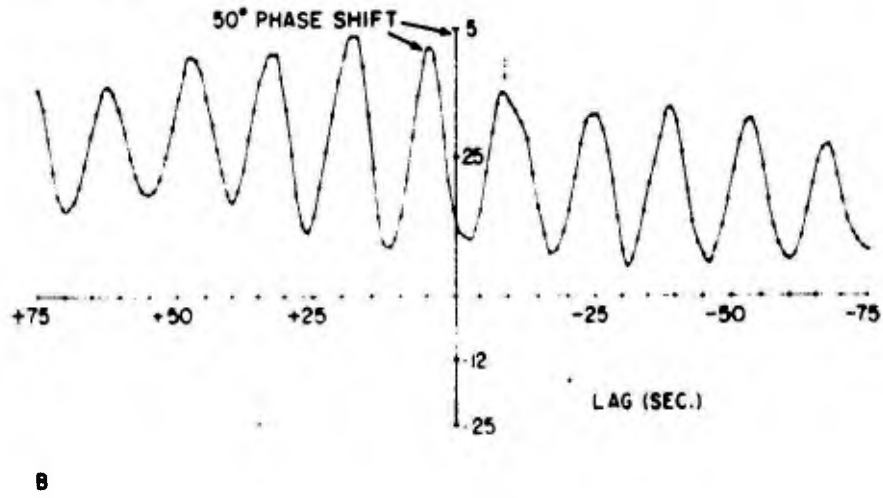


Figure 3

Records a & b



Records b & m



Records a & m

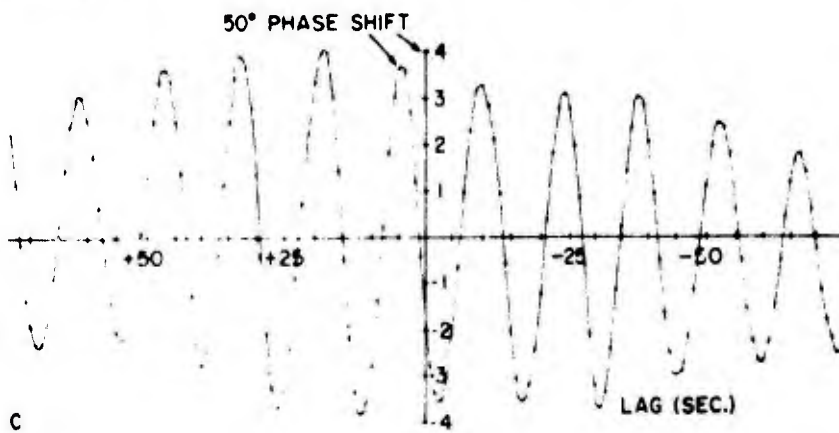


Figure 4

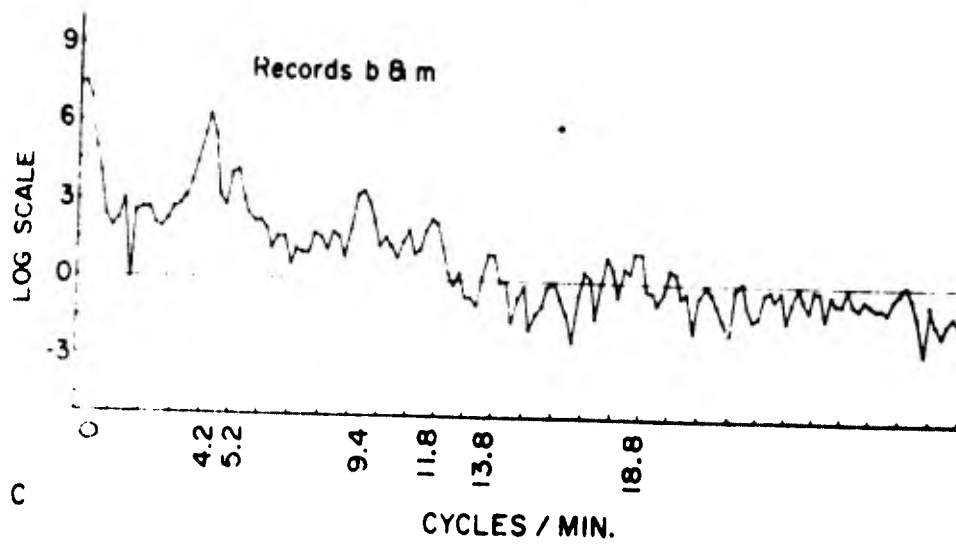
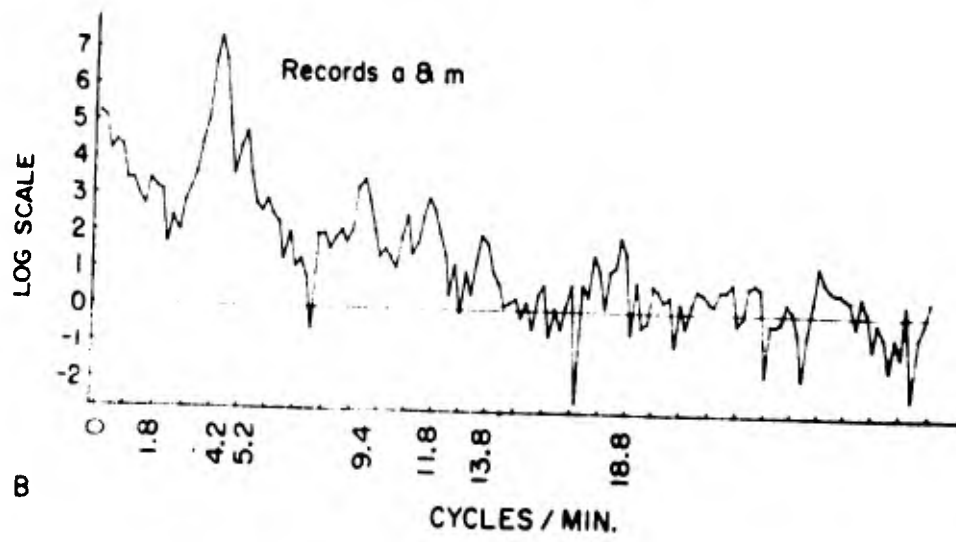
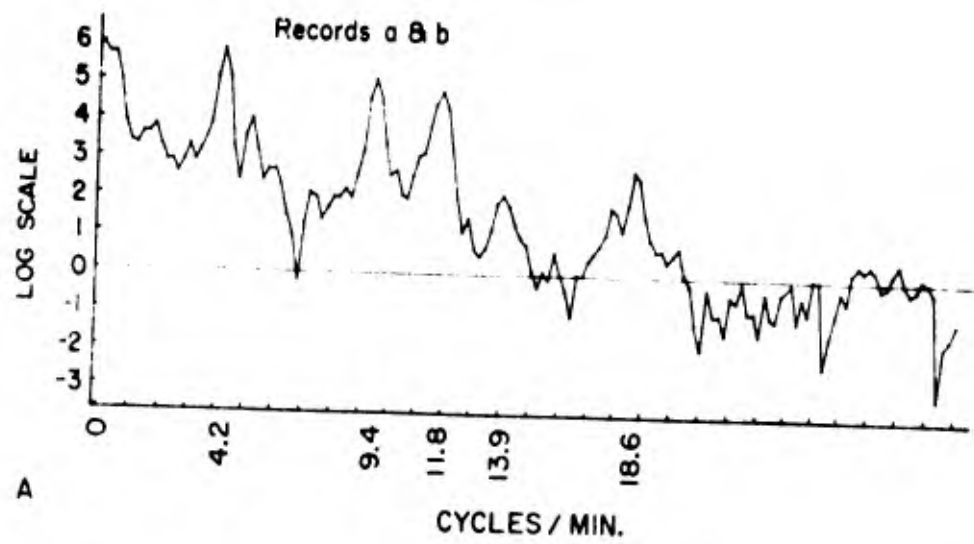
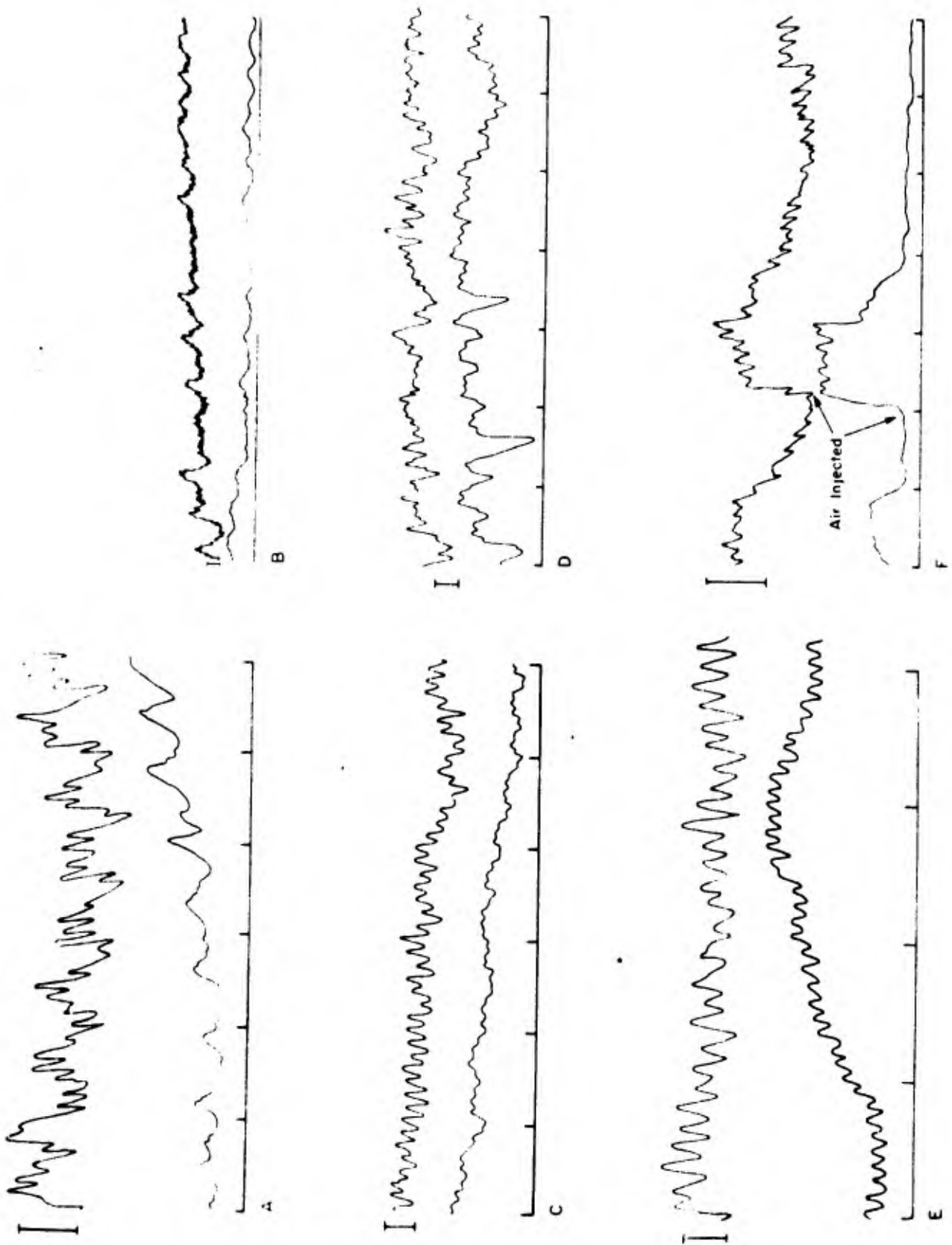


Figure 5



Voltage Bar = 2 mv.
Time Base = 30 sec.

Figure 6

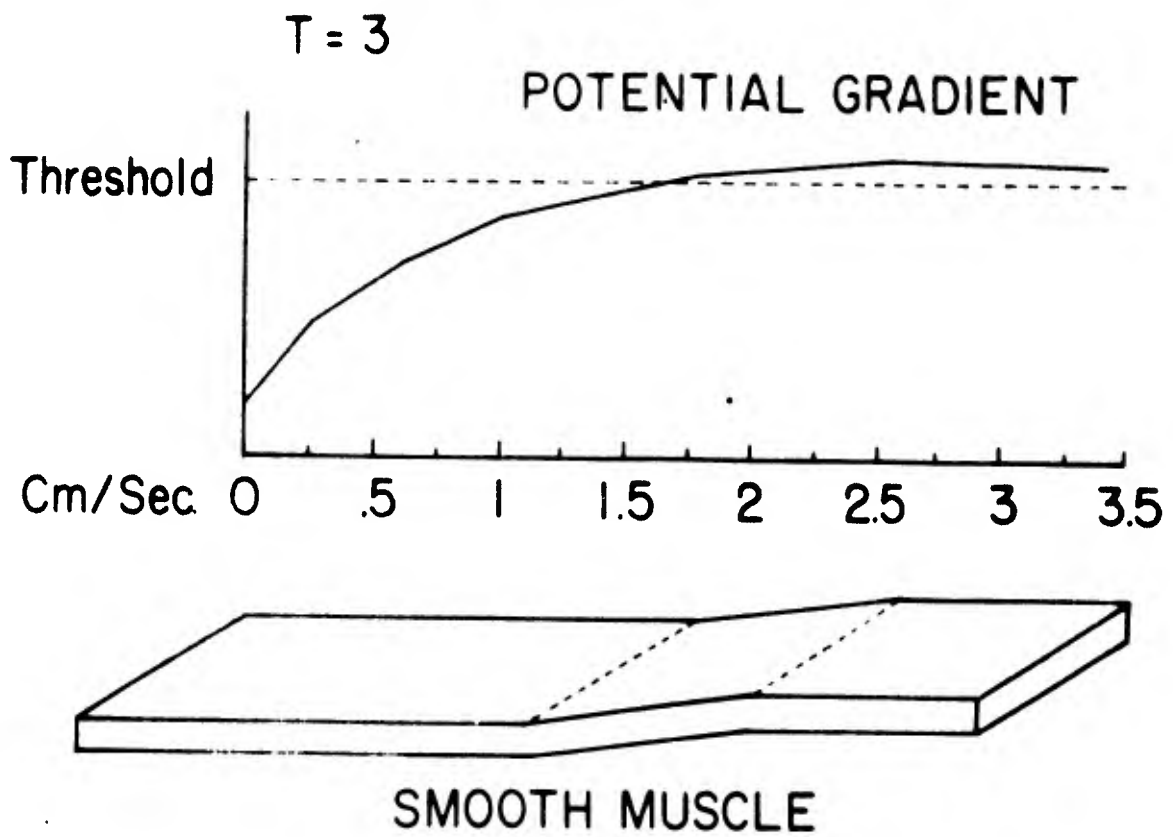
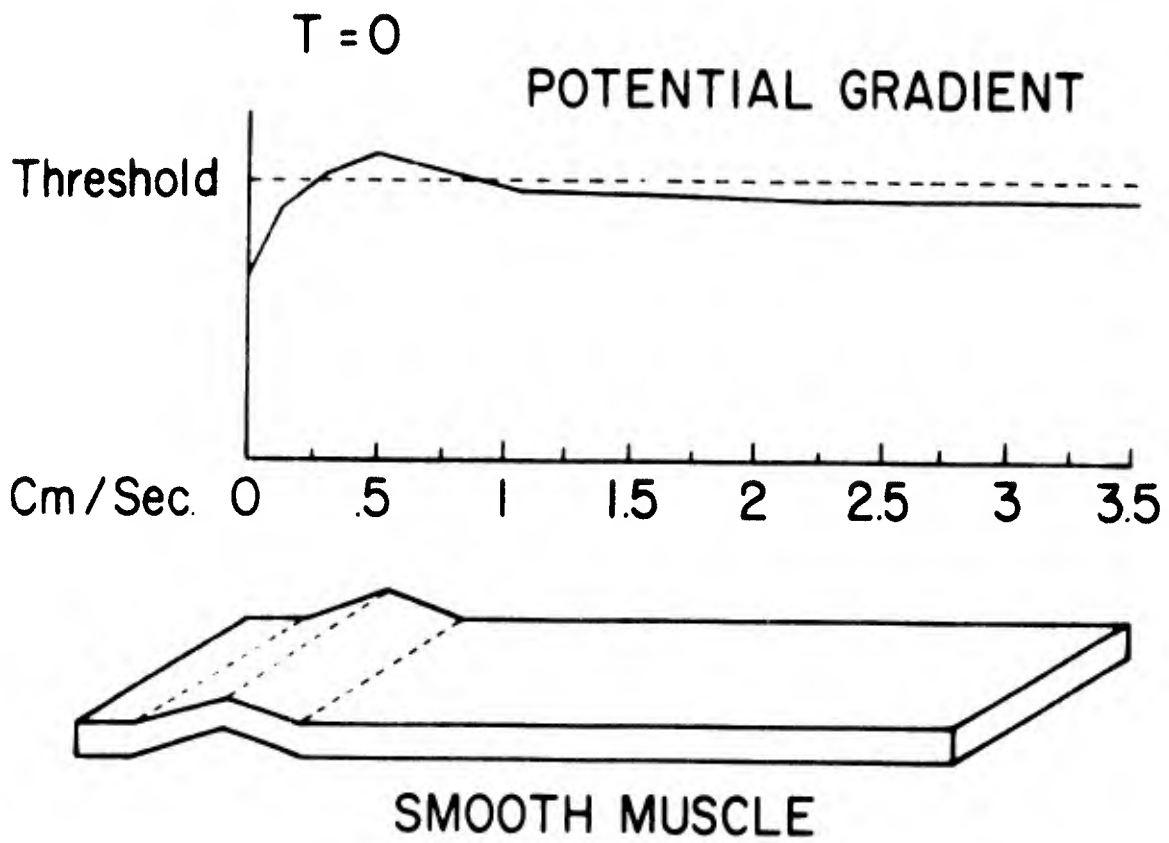


Figure 7

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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13. ABSTRACT <p>Reports in the American and Soviet literature have discussed the recording of electrical activity from electrodes on the surface of the abdomen (electrogastrogram or EGG) as a means of measuring gastric motility for research and clinical purposes. The complexity of the recordings has presented problems in analysis of the EGG and, hence, in specifying relations between it and other measures of gastric activity. The present report describes a method of pattern recognition which applies the techniques of autocorrelation and Fourier analysis to the reduction of this complexity and which provides information unattainable by more conventional methods. Further evidence is presented for the validity of the EGG as a measure of gastric activity: high correlations are demonstrated between frequency components of 3.5 to 5.5 waves per min. in simultaneous recordings of the EGG and of mechanograms obtained from strain gages sutured to the antral region of the cat's stomach. These correlations were found under both resting conditions and when gastric activity was manipulated by ip injection of physostigmine and Probanthine and by mechanical distention. It is suggested that other frequency components of the EGG are related to activity in the intestine.</p>			

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