A MODEL FOR DETECTION AND ANALYSIS OF INFORMATION PROCESSING MODALITIES IN THE NERVOUS SYSTEM THROUGH AN ADAPTIVE, INTERACTIVE, COMPUTERIZED, ELECTRONIC MUSIC INSTRUMENT

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July, 1975

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Rosenboom, D.(ed.): Biofeedback and the Arts: Results of Early Experiments, 2nd edition, Aesthetic Research Centre, Publications, P.O. Box 3044, Vancouver, British Columbia, Canada, V6B 3X5, 1975.

In 1972, York University provided funds for the establishment of a laboratory for investigating brain activity in relation to aesthetic experience. This lab has become the LABORATORY OF EXPERIMENTAL AESTHETICS in the Division of Interdisciplinary Studies, Faculty of Fine Arts, and is an official unit of the Aesthetic Research Centre of Canada, (A.R.C.).

The laboratory was conceived as an education-research project, using general systems theoretical approaches to the disciplined study of art media and their relationships to psychophysiological investigations of perception, conscious and unconscious states. This approach was precipitated, in part, by discoveries in biofeedback, which have vast implications for the self-awareness of and autoregulation of one's own perceptual and aesthetic sets. In addition, it was hoped that sufficiently powerful methodology would be developed to allow artists and experimenters to explore a large range of aspects of their own conscious or unconscious experiences with artistic environments and aesthetic situations and to find those physiological concomitants of these experiences that might provide useful tools for further study and design. Work by Rosenboom, Lucier, Teitelbaum, Eaton, Clynes, Munn, and others has shown that the significance of these discoveries to the making of art and the exploration of artistic processes is quite high. A large number of performances have been generated over the last four or five years in which the performers and, in some cases, audience members controlled the production of music, through electronic techniques, visual events, through electronic animation and video techniques, and environmental events by consciously manipulating or by simply allowing for the flow of their own brain patterns, electrical skin resistance, heart beat patterns, muscle movement patterns, and body temperature. Since then the idea has been extended to include participation by musicians, artists, actors, and dancers.

In the last three years, new projects at the LABORATORY OF EXPERIMENTAL AESTHETICS have demonstrated the capability of showing clear relationships between specific brain output patterns of a given artist and specific types of expressive, artistic activity. This work is supported by much of the biofeedback research done by many investigators in recent years and has been stimulated by important developments of Clynes (1) and John (2). In addition, it has recently become possible to isolate aspects of the brain's evoked response to sensory (artistic) stimuli, first, those that are associated with the physical aspects of the stimulus and, separately, aspects associated with the artist's conscious awareness of the stimulus and the information processing modalities he is using to interact with his stimulus (artistic) environment. These latter are called output releasing or readout component waveforms. Readout components are also seen during the imagining of an event or expressive action by an artist and are positively correlated with brain potentials that occure during direct experience of the event or a common mode of activity.

Clynes has shown that characteristic and highly repeatable response shapes or waveforms can be recorded from motor activity during the overt expression of a specific emotion or idea or during the physical articulation of rhythmic pulses in music from a particular composer. Analogous experiments in our lab indicate that equally characteristic waveshapes can be seen in the readout components of the brain's evoked response to an artistic stimulus or readout components associated with an overt expression by that artist. These units of expression as seen in brain and muscle signals are termed "actons" by Clynes. The mental image of a sensory event which, when elicited, can be associated with brain readout components like those associated with the occurance of the actual event in the environment are termed "idiologs". The internal state of the organism seeking expression through the outputting of "actons" is termed the "sentic state" and the form of the "acton" which expresses the "sentic state" is termed "essentic form". The successfulness of the expression depends to some degree on the purity and depth of relationship between the actual "acton" elicited and the true "sentic state" of the individual. (See "On Being Invisible" by D. Rosenboom, elsewhere in this volume.) Analogous studies from our lab indicate that a dictionary or cataloging of these "essentic forms" and associated prototypical brain output waveforms, which could be used to explore artistic experience and expression when combined with the biofeedback paradigm, would be extremely valuable.

Recent and current research is showing that the brain's evoked response to a sensory stimulus can be broken down and analyzed in such a way as to relate specific peaks in the evoked response waveform to specific aspects of either the stimulus itself or the processing behavior of the recipient. The evoked response is primarily dependent on two factors: 1) the physical parameters of the stimulus, and 2) the significance or meaning of the stimulus that is dependent on subjective experience. Affective meaning can significantly alter the response evoked by a stimulus. In an experiment by Bortin, Rimm, and Saltzstein (3) subjects were signaled by one of two tones that a bright or dim flash of light would soon be presented. Actualy, bright, dim, and medium intensity flashes were presented in random order. Changes in the response measured over the occipital cortex, (visual area, Oz), were assessed by measurements of peak-to-peak amplitude of the late component, negative peak, occuring at 145 to 165 msec. latency. Presentation of a bright and a dim flash yielded significant amplitude differences of this peak recorded both at Oz and at Cz, (vertex, top of the head). However, when medium intensity flashes, (signaled by untruthful tones ahead of time to set up expectancy), were presented, differences in amplitude, corresponding to the signal for an upcoming bright or dim flash, appeared only significant at the vertex, Cz. Subjects indicated by pressing buttons that they believed either a bright or dim flash had, in reality, occured. "The occipital evoked response is often regarded as related to, or concomitant with the specific processing of visual information and differs considerably from the responses recorded at the vertex, which are somewhat nonspecific and reflect a more advanced stage of information processing." (Bortin et. al.) It seems to reflect the activation of endogenous neural processes related to the past experience and present state of the organism. It has been proposed that these endogenous patterns of neural activity may reflect previous experiences and are in that sense released from memory rather than evoked.

Two quotes from Roy John may help here. "When an experienced organism receives a novel and meaningless stimulus and generalization occurs, this new afferent input in a familiar context activates the representational system in such a way as to cause release of a common mode of activity like that stored during the learning experience." And, later, "Analogous data from experiments with human beings indicate that phase-locked potentials are released at the time that absent stimuli are expected to occur. Furthermore, the waveshapes released when particular visual stimuli are imagined resemble the waveshapes of potentials evoked by actual presentation of the imagined stimuli."

"When an expected event does not occur, a brain potential appears at a latency similar to that of potentials usually evoked by the expected stimulus," (Bortin et. al.) A proposed term for them is emitted potentials or EP's. The term, endogenous, refers to late component events, released rather than determined by the afferent stimulus, and exogenous refers to earlier component events reflecting afferent input information. The experience of a specific stimulus and its associated "idiolog" is dependent on establishing those neurophysiological processes originally involved in the registration and coding of the stimulus in the first place.

Other studies (4) have shown that a late positive component (P3) of the auditory evoked potential, recorded at the vertex (Cz) is related to changes in d', which is a measure of the sensitivity of an observer to a particular signal, based on signal detection theory. This provides us with an approach to measurement which is sensitive to response bias and psychological variables as well as psycho-physical parameters. A current study by C. Mark Nunn of the LABORATORY OF EXPERIMENTAL AESTHETICS is showing that one may be able to use feedback indications based on an analysis of the changes in P3 as an aid in sensory fine tuning, for example, in pitch recognition. This may also apply to the tuning of any sensory filter and to adjustment of the correlation process that takes place between a sensory event or field of events and the formation of "idiologs" concomitant with those events. An increase in the intensity of P3 seems also related to an increase in confidence in the accuracy of a decision being made about a sensory event.

Still other studies show events concomitant with stimulus relevance. (5) The amplitudes of two peaks, labeled N2 and P3, seem to be related to the relevance of a stimulus in a given context or the appearance of a stimulus in the same sensory modality, (audition, vision, etc.), as that of the relevant stimulus according to the following scheme: 1) For the relevant stimuli N2 and P3 are large. 2) For irrelevant stimuli with the relevant stimulus being in the same sensory modality N2 is large and P3 is medium size. 3) For irrelevant stimuli in a modality different from that of the relevant stimulus both N2 and P3 are small or nonexistant. Thus, N2 is elicited by stimuli in the relevant modality, regardless of specific relevance. P3 is large if relevant, medium if irrelevant but in the same modality, and small or nonexistant if in the irrelevant modality. N2 may imply gating of the irrelevant modality or reflect a <u>preliminary</u> decision about the modality. P3 reflects some special cognitive processes invoked by psychological operations, independent of the physical aspects of the stimulus. P3 may be triggered by a definitive match between a sensory event and a neural template. This evidence supports the theory that early peaks of the evoked response reflect sensory processes (exogenous) while later ones reflect higher processing (endogenous), cognitive evaluation of stimulus significance. Stimuli of greater significance may evoke longer responses to the point of there being incorporated in the ongoing brain pulsation hologram, (ie. there integration times are very long and vary for events of differing significance as judged by the subject).

Still other studies show interhemispheric asymmetries that appear in response to changes in the meaningfulness of stimuli. (6) Bever and Chiarello (7) have reported a left hemisphere, (right ear), dominance in musicians who listen "analytically" to musical sequences and a right hemisphere, (left ear), dominance in nonmusicians who listen to the same sequences "holistically".

In further support of this, Hillyard et. al. (8) have shown P3 to be elicited only by signal tones that a subject was asked to detect, which were imbeded in a sequence of other tones and N2 to be elicited by stimuli in the relevant stimulus modality. Thus, N2 and P3 may reflect complex hierarchical filtering processes, (like the famous cocktail part effect in audition).

Another interesting approach lies in using a measure of electrical coupling between areas of the brain in various situations.(9 A measure of the coefficient of information transmission or uncertainty reduction between aspects of the waveforms measured from different areas is used. Measures in four experimental situations were taken: 1) reading a text, 2) examining details of a picture, 3) listening to Mozart, and 4) composing a letter mentaly with eyes closed. Some of the interesting results were as follows. Music caused significantly more coupling both for left and right than did any other test. Appositional processing of visual data tended to increase coupling between occiput and right hemisphere and positional processing tended to increase coupling between occiput and the left hemisphere. Significant degrees of observed coupling implies cortical synchronization between different areas.

These findings tend to support a statistical model of brain functioning rather than the traditional switchboard or patching models. The traditional theory was used by the early American behaviorists who contended that during learning a particular patch or "groove of increased excitability" along specific neuronal pathways was worn in and that memory functions involved the discharging of particular cells associated with specific patches or grooves. Thus, the place theory of memory and the localization of function theory of neuronal processes entered a period of general acceptance. Though it is still not entirely refuted, much evidence in the current neurophysiological literature points away from this view and toward a newer statistical model in which every neuron is influenced by all of experience, like each grain in the emulsion of a hologram is influenced by light quanta from every image impinging upon it. And, like a holophone, energy spectrum information about past experience and sensory events is stored but not the phase information. Phase information, however, can be reestablished merely by presenting the organism some small part of the original event which resonates with some part of the ongoing pattern and contributes to realigning the original phase relationships. This resonating stimulus may be internaly generated by ongoing hierarchical correlation processes with extremely long integrating time constants or may be externally supplied. An "idiolog", either newly formed or previously stored, is then released and an endogenous component appears in the evoked response. The positive and negative electrical peaks in the gross brain wave recording, then, must correspond to maxima and minima in a curve which describes the <u>probabilities of firings</u> among various groups of neurons.

The critical events in learning, then, are envisaged as those establishing representational systems of large numbers of neurons in different parts of the brain, whose activities are affected in a coordinated way by the spatiotemporal characteristics of the stimuli present during a learning experience. The coherent pattern is then capable of spreading to other regions of the brain or neuron ensembles. Changes that take place during experience and learning increase the probability of recurrance of a particular common mode of activity. One neuronal ensemble may represent many different coherent items, each with a different coherent pattern of <u>deviation from randomness</u> or from its baseline pattern. "By this process, the representational system acquires the capability of releasing the specified common mode of activity as a whole if some significant portion of the system enters the appropreate mode." (John)

Experimental evidence supports the theory as follows:

1) Widespread changes in evoked responses occur during learning.
2) There is a similarity of common modes of activity that occurs in different regions. After an unconditioned stimulus has become a conditioned stimulus, a new late component appears in its evoked response, resembling a tilted "W" with two negative peaks. As conditioning progresses, the waveshape becomes more complex and detailed in some structures, and later negativity becomes more pronounced. 3) Orderly firing patterns occure in extensive neural ensembles. Comparisons, carried out by Roy John, of microelectrode recordings from within the brain and surface recorded evoked responses indicate that positive and negative peaks in the averaged evoked response correspond to maxima and minima in the curve describing the probability of firing in the neuronal ensemble as a function of time after the stimulus. These patterns are widely distributed throughout the region as well. 4) Firing patterns depend more on the stimulus than they do on electrode placement. 5) Single cells have been found to display extremely variable responses to given conditioned stimuli while ensemble responses are essentially invariant. "Heterogeneously active elements converge to a homogeneously invariant average pattern." (John) The contention is supported that the same stimulus invariant response of an ensemble to a particular single stimulus will obtain for responses of single units averaged over many stimulus presentations.
6) Evidence supports the interpretation that the phenomena under discussion are closely related to the storage and retrival of information about the stimulus and to subjective judgmental mechanisms activated to deal with the stimulus information.

These ideas lead us in the direction of the use of high level, hierarchical correlation processes in extracting information for use in a biofeedback paradigm. We were, therefor, motivated to construct a lab that could provide for exploring some of the compositional, performance, and artistic design possibilities that this work suggests when combined with the concepts associated with biofeedback and related musical-artistic work of the last few years. Figure 1 shows the basic experimental equipment set up. It was designed for continuous use by artists and experimenters and allows them to explore an enormous range of aspects of their own conscious or unconscious interactions with artistic environments and aesthetic situations. It is intended to maximize capability for detection, measurement and analysis of bioelectronic signals that tend to be anti-entropic. Thus, much use is made of the Correlation Function Computer, which can give more information about signals than simple on-or-off detectors can, (like most Alpha detectors). It is also the author's contention that division of the EEG frequency spectrum into the categories of Delta, Theta, Alpha, and Beta has been much too arbitrary to rely on them alone in pursuing biofeedback experiments in the arts. They are, no doubt, useful, but limited in what they can tell us about neural information processing. For example, correlations between important acoustical parameters of a sound and the auditory evoked response of the brain are facilitated by this system. Measurements on the stability of Alpha waves and their amplitude variance have also been useful, as have methods for the detection of the modulation effect of a stimulus on high frequency cortical spike activity. (9) Experience also shows that giving feedback related to the appearance of coherent signals of any type or frequency may be more useful that simply detecting the presence of absence of energy in a particular, arbitrarily selected, narrow frequency band, (such as Alpha).

This type of thinking has led to a project to develop a new research and performance instrument, the functional diagram of which is shown in Figure 2. It is a general order detector, capable of searching for deviations from randomness or from baseline patterns with any amount of a priori instruction. The system may simply search for order, using pattern recognition techniques, or it may be steered by an operator who has ginen it previous instructions. He may be steering it by giving the computer feedback manually or from brain signals themselves. The instrument is capable of developing output languages, realized at present in the form of electronically synthesized sound, which reflect the principles of order that the system detects at its input part. In order to allow the operator to present maximum information, it is capable of extracting principles of order from any class of complex inputs, for example, signals from the brain and the nervous system, signals from transducers of physiological actions, other classes of waveform information, or compositional macrostructure specifications. It learns to extract large quantities of discrete and highly specific data from continous channels. A physiological gesture, neuroelectronic form, or series of such gestures or forms may be output by the human controller and are then broken down into a collection of discrete bits of information that can be applied to sound control. The instrument, then, organizes sound according to the principles of order it finds (recognizes) to be contained in the input stream. By "acting" them, the human controller effects production, through the instrument, of a sound analog of his expressive output.

The instrument becomes an extension of the brain and nervous system in the same way that a piano is an extension of the fingers, a specialized, highly personal paintbrush, with the added capability of being able to adapt its principles of operation to those of its performer-operator. In order to change its principles of operation, the performer-operator need merely change his own principles of operation and the instrument, presumably, will learn to understand them and follow. There is a history of such adaptive instruments. On early example is the cybersonic console, an electronic device constructed by composer, Gordon Mumma, for his now classic piece, Hornpipe. This instrument monitors the resonance patterns of its input, a modified French horn and the surrounding acoustic space, and changes its operating principles to complement these resonances automaticaly. Other developments of this type have been made by such experimenters as Lejaren Hiller and David Rothenberg, Max Neuhaus, and the group, PULSA, in the 1960's.

The system begins its analysis of brain signals according to a theory of their significance on a "primary processing" level as follows. The input stream, which is normally of a limited, low frequency bandwidth, (typically DC to 100 Hz or possibly 1000 to 2000 Hz when looking for modulation effects), is divided into four categories. The first is that of the continuous random/ quasi-random background of the universe of which the organism is a part and which reflects non-localized phenomena. The second and most difficult to deal with is that of the quasi-random phenomena that reflect localized processes within the nervous system. These are extremely complex, ordered phenomena that result from the experience of the organism and may be the end product of sumation or averaging of signals related to specific experiences in the past. Different weightings are given to specific events at various times. They reflect the anti-entropic tendencies of ordered, biological systems which increase in complexity and dimensionality throughout experience. They result from continuous pattern classification procedures, analytic activity, and proceed towards hyper-dimensionalit from a possibly non-dimensional life origin.

The third category is that of long term coherent phenomena. Long term, here, refers to anything with a coherence time of greater than approximately one or two seconds. Coherence time is measured by autocorrelation methods which involve multiplication of a signal by successive time delayed versions of itself and integration of the results. A curve is produced which is a function of delay and often appears as a damped sine wave. A measure of the amount of damping is used to obtain coherence time. It is into this category that the Delta, Theta, Alpha, and Beta waves fall. These phenomena are normally obliterated by background activity or by short term activity resulting from focused attention and concomitant idiolog formation processes. Abandoning these arbitrary frequency classifications for the moment, we see that the existence of any long term, coherent, sine-like phenomena is associated with some non-specific, activation state of the organism. There is a large degree of cortical synchronization and the nervous system may be prepared to react in a particular mode, but focused, subject-object processes are not active. The frequency of the coherent signals may relate to a particular mode of activation. High frequency, Beta-type, activity may indicate that the brain is prepared to react in a quick, logical manner very efficiently. Mid-range activity, like Alpha, is normally concomitant with strong consciousness of everything in the environment, but with no sensory filtering, making abstractions, or forming idiologs. It is akin to certain kinds of especially Zen-like meditation. Presence of uninterupted lower frequency activity, such as Theta, reflect deep, relaxed states more like types of Yogic meditation with low motor arousal. Still lower frequencies may reflect movement into unconscious states such as are found in deepest sleep and anesthesia. High frequencies seem to be concomitant with an extension of consciousness out into all parts of the somatic body, possession of the entire physiognomy by the psyche, and movement toward hyper-dimensionality. Lower frequencies tend to be concomitant with a receding of consciousness and the psyche into non-dimensionality possibly back towards the anterior end of the cerebral aqueduct and the posterior end of the fourth ventricle, out of which grow the third and lateral ventricles to form the forebrain and cerebral hemispheres during early pregnancy. (10)

The final category is that of the short term, (less than 1 or 2 seconds), phenomena that are associated with processing of stimulus information, formation of imagined images, and localized, normal, daily conscious activity. Considering an arbitrarily chosen point on a time line to be the present, we see the 500 msec. or so previous to this point representing effects of expectancy, typically seen in a strong negative shift, (contingent negative variation, CNV), in the EEG. The point corresponding to the present is assumed to coincide with the occurance of an environmental event to which attention may or may not be drawn. The first few msec. or so of the following phenomena represent primary processing stages of the stimulus information. The latter components of the identifiable waveform reflect higher cognitive processing, judgemental mechanisms, the formation of an image of the event (idiolog), and, possibly, release of readout components resonated within the ongoing quasi-random phenomena from category two or from memory.

After this initial categorization procedure the system proceeds to look for order and make correlations between inputs and outputs. To try to help with further illustration, the following is a functional description of just <u>one</u> of the ways that the instrument shown might be used. A subject (artist) connects himself, via skin electrodes, to the system. The synthesis system (electronic music), at the outset, is under completely random control. It will, thus, eventually output some sound. Relevant acoustical parameters of the sound are then compared with the response of the brain to the sound by the cross-correlation function computer and further analyzed as to frequency and energy content by Fourier transform methods. If the response is considered significant, (ie. crosses a threshold), important information from the analysis of the waveshape is stored in an associative array memory. Then, the synthesis system produces another sound and it is compared to the brain's output in a manner similar to the first stimulus. If this response is deemed significant, information about its waveshape is compared to everything that has built up in the system's memory array. If there is a positive correlation between the new response and something in the memory, the synthesis system is told to increase the probability that the sound patterns eliciting the response will occur again. Similarly, if the frequency of occurance of a strong response to a pattern decreases, so the probability of occurance of the associated sound patterns decreases. Thus, the sound pattern producing system, (this might be visual as well), is tuned (convergence) toward those classes of patterns and classes of relationships among patterns that are associated with the response of interest. One may then proceed by performing music, trying to apply principles of biofeedback control to the situation, do research in perception of sound patterns, simply explore naturally occuring relationships, etc.

Patterns build up, then, as significant, (attention securing or not, depending on intention), stimuli are generated, at first by chance. Behaviours of the system build and extinction is also possible. Information from the Fourier analysis can be used to program an adaptive filter that will, then, extract exactly the waveform of interest from future signals for feedback purposes or for purposes of cataloging in a dictionary of "essentic form".

In addition, it is useful to be able to correlate between EEG outputs and "sentic states", (as described by Clynes). For example, Figure 3 shows a set of waveforms recorded from a method actor who was attempting to summon up within himself a repeating cycle of emotions, moving from love to reverence to rage to grief. The ~~lower~~ upper trace in each pair is a continuous autocorrelation of his brain wave and the ~~upper~~ lower trace is a Fourier analysis, (abscissa spans a range of DC to 100 Hz). These may change from individual to individual but seem stable for one subject during a given session. The experience of such intense practice of a sentic cycle like this is quite powerful and of considerable interest. The characteristic brain output patterns may help us in constructing further interface. A quasi-translator of "essentic form" may be constructed, then, to investigate proto-sentic states. Another interesting view of this instrument is that it is capable of conducting research on its performer during an actual musical performance process.

The system herein only generaly described is being designed and implemented by the author with generous assistance by Don Buchla of Buchla Associates, Inc. and others at the LABORATORY OF EXPERIMENTAL AESTHETICS, A.R.C., and York University and an applications program is being supported by the Canada Council, Explorations Program.

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Additional Background Material

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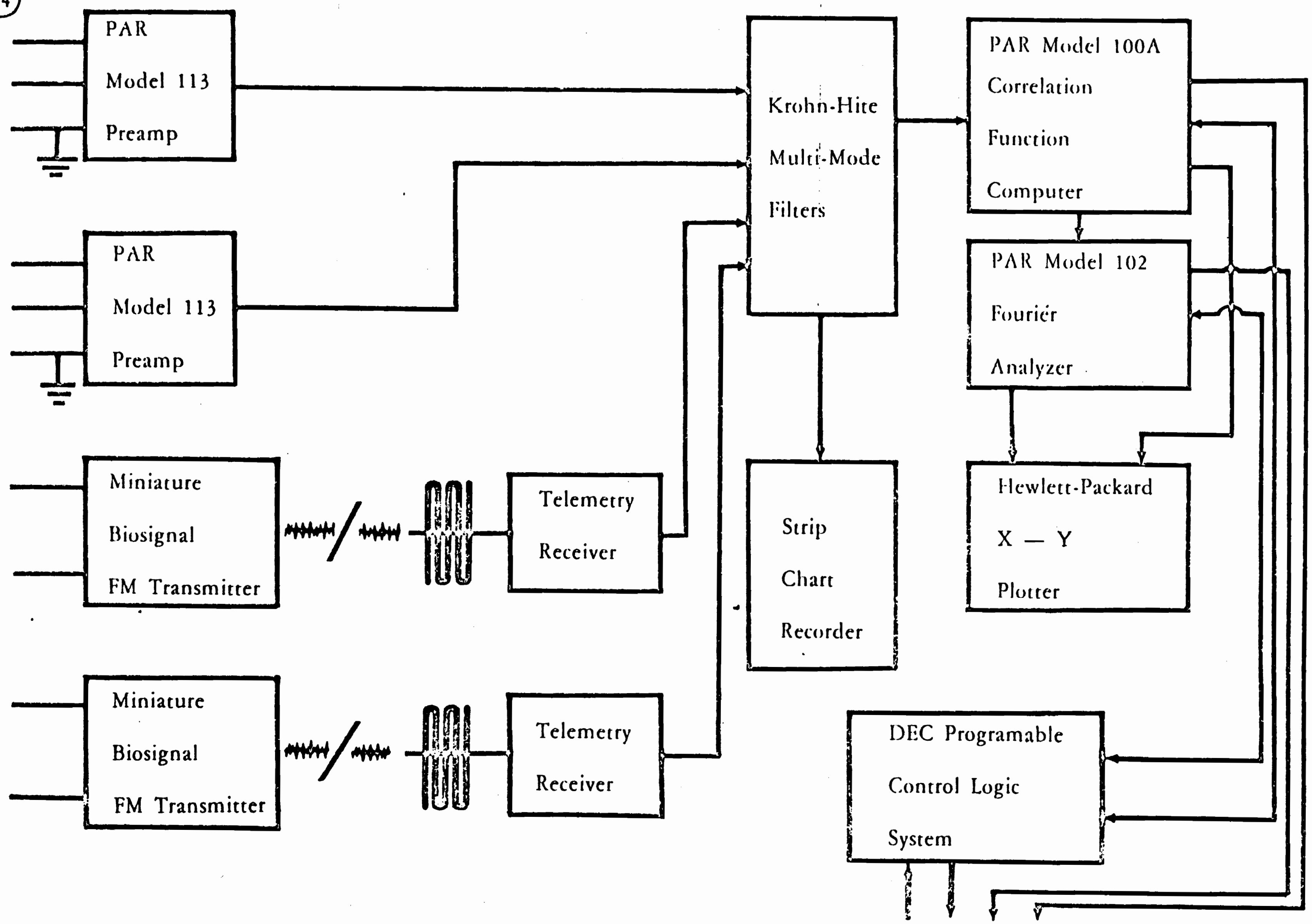

Figure 1.

To interface with ELECTRONIC MEDIA STUDIOS' musical and visual synthesis systems and computer.

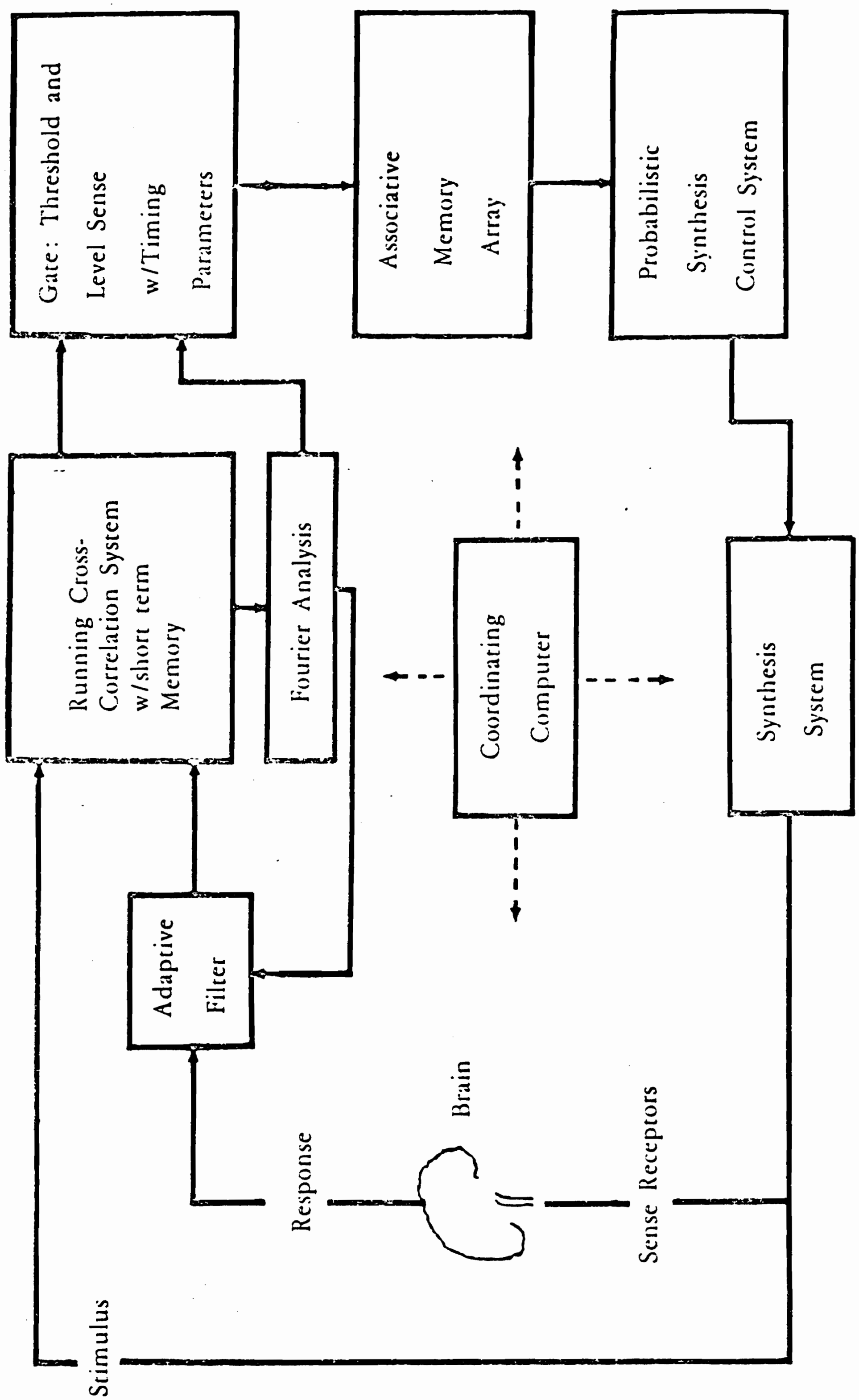
Gate: Threshold and
Level Sense
w/Timing
Parameters
Associative
Memory
Array
Probabilistic
Synthesis
Control System
Running Cross-
Correlation System
w/short term
Memory
Fourier Analysis
Coordinating
Computer
Synthesis
System
Adaptive
Filter
Brain
Response
Sense Receptors
Stimulus

Figure 2.

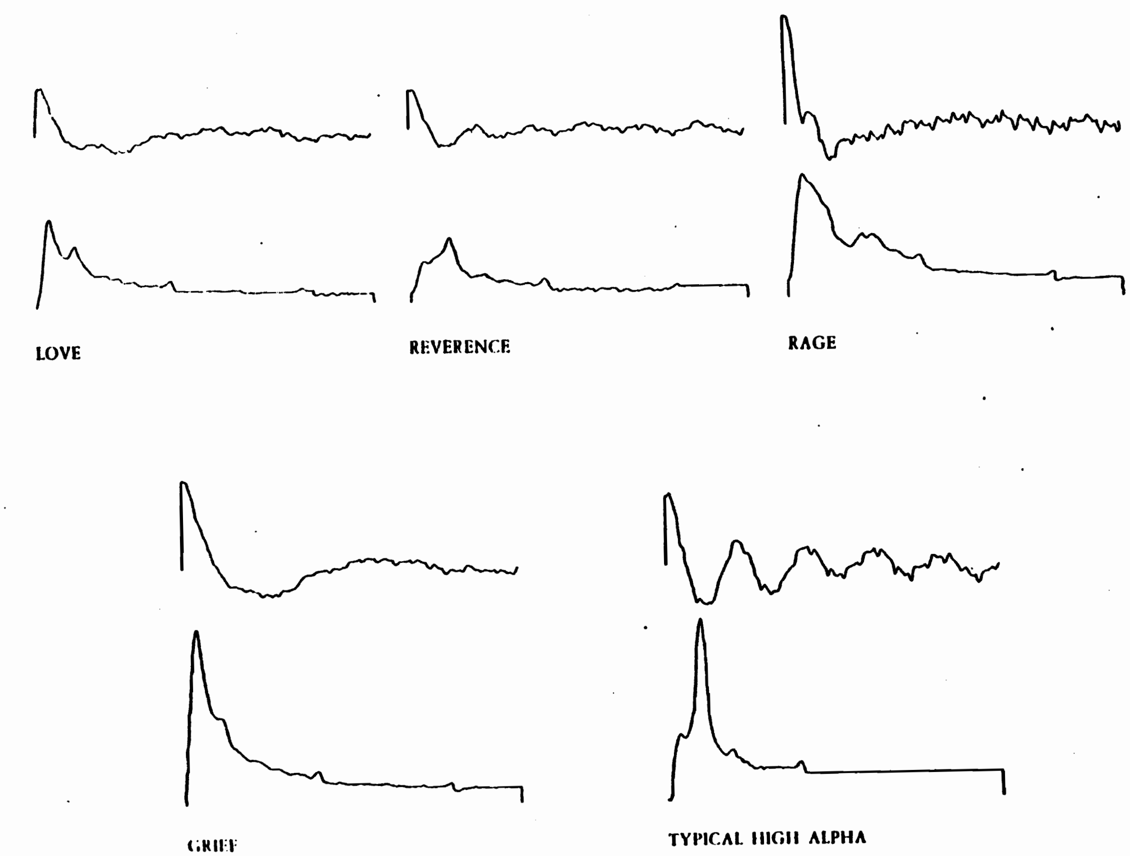

FIGURE 3

Waveform pairs showing auto-correlation, upper trace, and Fourier analysis, lower trace, of continuous EEG recorded from a method actor who was practicing a short, repeating "sentic cycle." Both curves of a given pair were computed continuously for the same EEG epoch and printed after 100 sec. analysis. The actor then proceeded to the next emotion in the cycle. Delay range is 500 msec. for auto-correlation and integrating time constant is 20 sec.

Abscissa scales are 100 msec. delay/inch in the auto-correlation graphs and 20 Hz/inch in the frequency domain, Fourier analysis graphs. Ordinate scales are amplitude for both graphs, 0.5V/inch output from PAR Correlation Function Computer and Fourier Analyzer. Computation is done in real time. Traces on the lower right show an example of typical waveform pairs obtained from subjects who have high Alpha output.