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THE STATE-OF-THE-ART OF ELECTROENCEPHALOGRAPHY AND ITS ROLE IN MANNED SPACE FLIGHT

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SUMMARY

This report is a collection of opinions concerning the state-of-the-art of the electroencephalogram for answering the question: How competent is man during his flights into space?

The initial step in an attempt to answer a biomedical question which lacked reliable experimental data was to seek the opinions of scientists who were recognized scholars in the field of neurophysiology in general and in electroencephalography in particular. The following is a summary of their considered opinions.

1. The E.E.G. (the electroencephalogram) is a highly reliable index for the state of vigilance.
2. The E.E.G., in its present stage of development, is not a direct indicator of competency.
3. The E.E.G. can give inferential indications of competency.
4. Test-stimuli techniques would provide more direct evidence of performance and decisional procedures.
5. The E.E.G. could serve as a supplement for verbal communication.
6. The E.E.G. has demonstrated usefulness in the investigations of biorhythmicity.
7. Techniques for collecting electroencephalographic data under conditions which simulate aspects of space flight are being developed.
8. Techniques are being further developed for analyzing and for plotting electroencephalographic data.
9. The recent advances in the methods for studying data retrieved from electroencephalograms indicate potentialities for evaluating decisional processes.
10. The use of electroencephalography as an answer to the question of competency awaits a better solution to the problems of data reduction and display.

THE STATE-OF-THE-ART OF ELECTROENCEPHALOGRAPHY AND ITS ROLE IN MANNED SPACE FLIGHT

A. INTRODUCTION

The state-of-the-art of electroencephalography is in a condition of flux because of the recent technological advances in the methods for processing neuro-electric data. One major motivating influence for accelerating these recent advances is the increasing emphasis on manned space flight programs.

How competent is man during orbital flight? The purpose of this report was to seek an answer to this question. Since competency is defined as functional adequacy, some clue to this adequacy may be found in monitoring the nervous system, particularly the electrical activity of the brain. A search for a possible answer to the above question was made, therefore, in the field of electroencephalography. Unfortunately, no electroencephalograms of our astronauts have been recorded during flight. This report contains the opinions of scientists recognized generally for their contributions to the field of neurophysiology and psychiatry, and is an attempt at answering the above question.

The Soviet open literature [1/] contains information obtained from electroencephalograms recorded during several flights of cosmonauts by placing silver electrodes on the forehead and occiput. The objective in studying the electroencephalograms was to search for a relationship between particular variations in the EEG measurements and the overall condition of the cosmonaut in orbital flight.

1/ Medical and Biological Research on Space Vehicles "Vostok" and "Voskhod." A Translation.

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B. SURVEY OF OPINIONS

The information contained in this report is a collection of answers to the following questionnaire.

1. How competent is the man in the space vehicle for executing his role as the human component in the overall vehicular-plus-ground systems?
2. Can he make the correct decisions?
3. Can he translate these decisions into the action required?
4. What can be learned from the electroencephalogram for answering these questions?
5. If data supplementary to the electroencephalogram are needed for a more reliable and complete answer to Question 4, what parameters are required for supplying these data?

The recipients of the questionnaire were well recognized scientists in the field of neurophysiology and its related disciplines (see Appendix). The answer to only one question, namely Question 4, was requested. The desirability of an answer to Question 5 was indicated.

The questionnaire was mailed to 31 scientists; replies were received from 18. Five of these 18 respondents stated that either they were no longer active in the field or that their particular research was not pertinent to the requested information. One scientist stated that his research is confined to animals.

Table I summarizes the replies to the questionnaire.

TABLE I

SURVEY OF SCIENTISTS' OPINIONS

Scientist	Reply to Question 4	Reply to Question 5	Additional Comments by Scientist
Adey	Only recently has the requisite technology been available for collection of the E.E.G. under conditions of environmental stresses similar to those encountered in space flight. It is considered that the E.E.G. can provide a highly reliable evaluation of the state of alertness, drowsiness and boredom, in incipient sleep and an accurate evaluation of the depth of sleep under conditions of actual space flight.	Studies of: 1. Eye Movements 2. Electromyographic Records 3. Galvanic Skin Response 4. Heart Rate 5. Respiration	The scientist doubts whether any appeal to punditry can truly evaluate the use of the E.E.G. in this (manned space flight) area.
Barlow	Most likely contribution of the electroencephalogram would be as a monitor of the state of alertness of a man in a satellite. Another contribution is in connection with the study of the sleep-wakefulness cycle of a subject in an orbiting satellite.	Nothing to suggest save for possible quantitative determinations of reaction times as related to points made in answer to Question 4.	Scientist considers that he has no particular competence in this area.
Bickford	A candid answer would be "nothing". The E.E.G. is one of the best measures of vigilance and in this respect is perhaps only second to a performance test that would give a vigilance index by some kind of response from the subject.	No reply	Their (referring to the questions) naivete is profound.
Brazier	A very great deal!	No reply	No additional comments.
Halberg	A study of spectral variance shifts in the frequency analyzed E. E. G. might be a reasonable dividend from monitoring human E.E.G.'s during flights in extraterrestrial space. A need is emphasized for a correlation between variance shifts in the circadian and ultradian domain of electroencephalographic frequencies with performance parameters, such as decision time, in the course of ground work ---- before such plans are incorporated into bioastronautic planning.	No reply	In our laboratory we have already extensive though unpublished evidence for the presence of an ultradian band (frequencies with one cycle in 3-5 hours) as well as of a circadian one in the human electroencephalogram.
Krendel	The opinion is given that questions 1, 2 and 3 can be answered more adequately directly rather than by an intervening variable such as the E.E.G. might supply. Several papers indicate how question 1 can be answered directly. Two such references are: 1) McRuer, D. I., Ashkenas, I. L., and Krendel, E. S., "A Positive Approach to Man's Role in Space", Aero/Space Engineering, Vol. 18, 1959, Pages 30-36. 2) Mcruer, D. T., and Krendel, E. S., "The Man-Machine System Concept", Proc. of the I. R. W., Fiftieth Anniversary Issue, Vol. 50, No. 5, 1962, Pages 1117-1123.	No reply	Not active in E.E.G. work for at least five years.

TABLE I. (Continued)

Scientist	Reply to Question 4	Reply to Question 5	Additional Comments by Scientist
Rowland	Gross changes in the E.E.G. of aviators which appear like abnormalities in some cases of epilepsy have been observed in actual flight; changes with angular accelerations, gravitational stress, etc. These changes are not known by the scientist to have been correlated to any great extent with objective performance tests. Recent advances in computer analysis of the E.E.G. have not established the usefulness of such analysis over other potential technics for monitoring astronaut condition. Artifacts are caused by speech and jaw movements, chewing, teeth clenching, etc., which contribute tremendous noise. Noble efforts at telemetering brain activity from permanently implanted intracerebral electrodes may some day give at best a hint about the refined parts of an astronauts condition and capacity. Such efforts, in Sem-Jacobsen's opinion, would be far less rewarding than programming, at frequent intervals, test stimuli delivered to the astronaut, calling for behavioral responses, the latencies, accuracies and other features which give a direct performance evaluation and leave no doubt of various performance parameters. The test-stimuli techniques would be more direct, sensitive and accurate than could be provided by presently known practical electroencephalographic technics.	Reply to this question is involved in the reply to question 4.	This scientist gave a similar opinion some five years ago to the Thompson Ramo Wooldridge Company which antedated the study by Sem-Jacobsen. Although not even an approximate coverage of the large literature is claimed, the scientist feels that no substantial developments have been made to change the opinion given at that time. The replies have been retrieved from a report by Sem-Jacobsen which accompanied the scientist's reply.
Lindsley	Ways in which E.E.G. might be useful: 1. Selection of candidates for orbital flight 2. The standard E.E.G. has not, to the scientist's knowledge, been particularly useful with regard to decision processes *per se*, except as an index of whether a subject is getting drowsy or going to sleep which would preclude appropriate decisions. 3. The E.E.G. is being applied to studies of vigilance, attention, expectancies and anticipations; processes which are involved in decision processes and thinking. Many psychophysical and behavioral methods for assessing ability to make perceptual discriminations are in the stages of development.	No reply	Questions 4 and 5 relative to questions 1, 2 and 3 are difficult unless some other conditions of orbital flight are provided.
McCulloch	An E.E.G. can give evidence to attention, general alertness, drowsiness, sleep, coma and convulsions, the former facilitating and the latter disturbing the competence of man in space in decisional processes and his ability to execute what he intends. To be of maximal use you should know the brain waves of the particular astronaut under conditions of stress, relaxed and sleep.	It is assumed that E.K.G. and respiration will be noted. Until cockpit design has evolved and flights are routine, it would be very useful to know the direction of gaze or at least its transients which could be easily recorded on two channels chopper-stabilized for D.C. recording.	No additional comments.

Opler	Range of variation in "normals" of the E.E.G. suggests that total personality be evaluated by other techniques. E.E.G. is just a crude screening measure which picks up gross neurological disabilities.	Knowledge of the personality, social relationships and total evaluations of a social psychiatry sort. This procedure includes projective and objective tests. A broad battery was constructed by this scientist in the Midtown Manhatten Studies.	Questions 1, 2 and 3 depend on total personality balance, but that can be evaluated by various measures which go beyond E.E.G. criteria.
Rosenblith	Views of the scientist on the general area as implied in the following two publications: 1. The quantification of neuroelectric activity, Chapter 1, in a book entitled, "Processing Neuroelectric Data", edited by the scientist and published by M.I.T. Press, 1959; 2nd printing 1962. Pages 1-11. 2. Walter A. Rosenblith, Commentary, Pages 88-93. Computer Techniques in E.E.G. Analysis, Elsevier Publishing Company, Amsterdam. Comments by Vista: Reference 1 is an excellent review of the status of data-processing facilities available to the student of the nervous system or of human behavior (at the time of this publication). Following the introduction the author devotes the remaining pages to two considerations, i.e., "Problems of Measurement and Analysis in Electrophysiology" and "A Statistical View of Neuroelectric Phenomena". Reference 2 is a critical discussion of a conference which emphasized methods of data processing by means of computers. Applications for studying the brain and behavior were the major interest.	No reply	"I received................the not terribly explicit questionaire".
Saunders	The E.E.G. is not a direct indicator of mental status or perceptive or motor ability. It can however, give inferential evidence concerning these.	E.K.G., E.O.C., Psychogalvanic response.	References will be supplied if desired (statement by scientist).
Sem-Jacobsen	Answer to Questionnaire was indicated as follows-- quotations from letter dated August 11, 1964: "These questions have been in the center for my research for the past six years, which started with my studies in jetfighters and lately has been continued for NASA in connection with space flights. "Currently under contract with NASA, we are making equipment which will give a much more complete answer to the vital questions you are mentioning than any of the answers we so far have been able to give. "If I therefore can delay my answer on your letter with about a month*, I will be able to give you a more substantial answer than I can today. My current study is to be completed in about three months." *This letter was not received. Reprints of the following papers were enclosed: 1) Carl Wilhelm Sem-Jacobsen, M.D., Electroencephalographic Study of Pilot Stresses in Flight, Aerospace Medicine, November 1959, Pages 797-801. 2) Carl Wilhelm Sem-Jacobsen, M.D. and Ingebjorg Elisabeth Sem-Jacobsen, Selection and Evaluation of Pilots for High Performance Aircraft and Spacecraft by Inflight EEG Study of Stress Tolerance, Aerospace Medicine, Vol. 34, No. 7, July 1963. 3) C. W. Sem-Jacobsen, M.D., E. Kaiser and I. E. Sem-Jacobsen, Collection of Biological Information during Prolonged Flight Missions with "Yes and No" Data Reduction Analysis. Paper presented at 35th Annual Mtg. of Aerospace Medical Assn, May 11-14, 1964, Miami, Florida.		Quotations from letter dated May 28, 1965: "I have one paper that I presented at the School of Aviation Medicine in November 1964, which will be out in print very shortly. You may be able to obtain a copy from Colonel Ellington at the school. "I also presented a paper dealing with the same topic at ORT at NASA Headquarters in November 1964. "I am currently making a report about the subject but I think it will be better that you just mention that I am writing a report and refer to it as such. I think this is the best way to avoid any misunderstandings or misquotes."

C. SUPPLEMENT TO TABLE I

When replying to the questionnaire, a few of the scientists included pertinent information supplementary to an immediate answer to Question 4. Extracts from the letters of these scientists are presented here.

1. Submitted by Saunders

Question 4.

Preliminary Considerations. The EEG is not a direct indicator of mental status or perceptive or motor ability. It can, however, give inferential evidence concerning these. During waking states probably the maximum amount of information concerning mental, perceptive and motor status is obtainable through verbal communication and command - response situations. If long duration flights are planned with man as an active participant, then either continuous verbal communication or a continuous monitoring system to directly or indirectly indicate mental status of key personnel is necessary.

Since much information may be obtained by continuous verbal description of procedures by the key personnel during critical periods, monitoring by other methods can be avoided. However, to do this, considerable subjective interpretation of the voice, its inflections, choice of words and the like may be necessary. Checking of responses of the vehicle to adjustments, stated to have been made is necessary and little evidence of impending changes in levels of consciousness are available until they have occurred.

Since the EEG is a fair indicator of levels of consciousness and since levels of consciousness reflect perceptive and motor ability, the EEG can give good inferential evidence of behavioural ability during periods when verbal communication is not maintained. As there is evidence that EEG changes can precede behavioural change, indication of impending impairment is possible.

The EEG now becomes a supplement to, not a substitute for, verbal communication. Periods when verbal communication is absent may be monitored and the level of consciousness during verbal communication inferred. Other additive evidence can be obtained by monitoring other systems (see Q.5). It may be seen that this investigator believes that the EEG has a useful function in monitoring man in space although the proviso must be added that if evidence of changes in behaviour is inferred, some form of control of the vehicle from ground to substitute for man would be of value. Being able to infer change in consciousness and unable to help would be interesting but somewhat academic and use up communication channels available for other purposes.

It is not too difficult to transmit eight channels of EEG data over a 5000 c.p.s. bandwidth. Some methods of data reduction are available although much work remains to be done in this field. Any data reduction or transformation (e.g. frequency analysis) must be performed in real time. Data should not be collected in epochs of more than one second before presentation. Rather, instantaneous presentation as in the conventional EEG or presentation after frequency filtering is necessary. It is not the purpose here to discuss computer methods of pattern recognition which is still in a very limited state. At the moment, monitoring requires continuous visual examination of the EEG by a trained observer. This in itself is a limiting factor since continuous visual examination is extremely tedious and short episodes of not watching during critical periods could be disastrous. It is felt there are techniques of overcoming this.

EEG Activity. Assuming the validity of arguments that the EEG can be of considerable value, some indications of its capabilities and limitation may be outlined.

During alertness with the eyes open the great majority of normal adults show little consistent activity in the EEG. Some theta activity (4-7 c.p.s.) may appear in certain electrode montages involving the temporal lobes and some beta activity (< 14 c.p.s.) in the motor regions. The EEG is not flat. The amount of beta activity may increase during periods of heightened alertness and the theta activity may increase during anxiety. Kappa activity (around 10 c.p.s.) may appear in the temporal areas during mental concentration. Quantitation of these changes by visual examination is usually very difficult. Techniques could be developed to explore the significance of the patterns more fully than at present.

During non-alertness with eyes open, i.e. day dreaming and focussing on infinity, alpha activity (8-13 c.p.s.) of low amplitude usually appears sporadically. That is, this pattern indicates a state of lowered visual perception. When the eyes are closed, alpha activity appears in the majority of normals. The presence of alpha activity implies reduction or absence of visual reception. There is also evidence in the literature that conditions that reduce the mean alpha frequency tend to increase the reaction time. Interestingly, long term sensory deprivation tends to reduce the mean alpha frequency quite markedly. The degree of visual alertness may be inferred from the EEG and on comparing long term mean alpha frequencies, some inference of reaction time change is obtained.

Should the astronaut doze, quite marked changes in the EEG would appear particularly in levels of theta activity. As sleep progresses a variety of well described changes appear and the sleep level may be quite accurately assessed.

Unresponsiveness due to sleep as compared to that due to some pathological state is usually possible. Use of peri-orbital electrodes to detect eye movement can give good confirmation of sleep. K complexes produced in the EEG by some stimulus can give further confirmation. The presence of the K complex during sleep will give confirmation of the reception of the stimulus and imply integrity of the earth vehicle communication channel. Return to the waking state and alertness can be followed.

Should some situation arise impairing cerebral metabolism (e.g. anoxia), the alpha activity decreases in frequency. The theta activity increases in amplitude and spreads to areas of the brain not normally producing these patterns. In the early stages of appearance of this activity, the astronaut may well appear alert on verbal communication but there is evidence that at least in visual-motor performance the error rate will increase quite markedly. The inference is that judgment in critical situations will be inadequate.

Ability to differentiate physiological from pathological changes in alertness is possible particularly if other parameters are monitored (Q.5).

Should the EEG go through a series of changes to very slow activity, suppression burst activity and ultimately to no activity (flat EEG), there is evidence of death or impending death. Absence of heart beat would confirm this incontrovertibly.

It may be seen that from the EEG a considerable amount of inferential evidence concerning the well being of the monitored human may be obtained without two-way voice contact being necessary.

Question 5.

Other Parameters. To support evidence from the EEG a variety of physiological parameters could be monitored. Here their function will be considered primarily as evidence to support EEG findings.

EKG - increase in rate can indicate anxiety or some generalized pathological effect (e.g. anoxia). Increase in heart rate plus increase in beta activity is strongly suggestive of anxiety. Increase in rate, T wave inversion plus theta activity in the EEG is strongly suggestive of some impending pathological condition. Decrease in rate plus increase in theta activity suggests drowsiness. Marked slowing, T wave changes and very slow EEG activity suggests a profound toxic effect.

Electrooculogram - electrodes around eyes to detect eye movement and eye blinking.

During relaxation there is a tendency to frequent blinking and eye wandering. In alert states blinking decreases and eye movement tends to follow specific patterns (e.g. checking instruments).

During sleep and dreaming eye movements will appear, but during coma these will be absent or infrequent.

The psycho galvanic response can add evidence concerning states of anxiety, relaxation, sleep or pathological conditions.

All the above may be monitored by visual inspection of a trained observer and the correlations of the data made mentally. Given time and money, there seems to be no reason why most of the correlations should not be performed by computers.

2. <u>Submitted by Lindsley</u>

The questions you pose with regard to the electroencephalogram (EEG), that is, Nos. 4 and 5, relative to Nos. 1, 2 and 3, are difficult unless some other conditions of orbital flight are provided. For example, can one assume that relatively normal levels of oxygen and carbon dioxide tension will be maintained, and that blood sugar level, etc. will not fall below normal limits? What levels of ambient noise and temperature are involved? Under conditions of weightlessness what degree of proprioceptive feedback is lost? I presume that answers to these and other questions are known within certain limits but I do not know them offhand.

Ways in which I would conceive that the EEG might be useful, without having given much preliminary thought to this question, are the following:

1. Selection of candidates for orbital flight to insure that: a) they are free of epileptic or convulsive tendencies and possible other brain abberancies; b) testing limits of physiological stress by breathing low oxygen mixtures to near point of unconsciousness; by hyperventilation or other means for reducing carbon dioxide level; under conditions of low and high blood sugar levels; c) testing EEG and possibly autonomic responses under conditions of psychological stress; d) noting effects of weightlessness on EEG, perceptual capacities, motor performance, etc.

2. With regard to decision processes *per se*, the standard EEG, has not, to my knowledge, been particularly useful, except as an index of whether a subject is getting drowsy or going to sleep, which of course would preclude appropriate decisions. (Some work is being done on animals with electrodes implanted in various structures of the brain in an effort to determine changes occurring during perceptual discrimination and learning, and some identified with decision processes once a habit has been learned.)

3. Use of the EEG in conjunction with average response computers for studying evoked potentials to visual and auditory stimuli, indicates that this may be a useful method of studying vigilance and attention (References)* over time; also recent work suggests that it may be useful in studying expectancies and anticipations, processes which of course are involved in decision processes and thinking.

The limits of usefulness of the EEG in 1.) above depend entirely upon what questions one is trying to answer and what conditions will be imposed. There are many sources of information depending upon the conditions. Briefly, I think some of my own summaries of changes in the EEG with regard to physiological and psychological factors leading to shifts in level of consciousness or awareness (i.e. alertness, attention, drowsiness, sleep, loss of consciousness) might be helpful starting points. Two such references among others are:

Lindsley, D. B. Electroencephalography. In: J. McV. Hunt (ed) Personality and the Behavior Disorders, Vol. II, Chap. 33, Pp. 1033-1103. New York: Ronald, 1944. (See particularly pages 1054-1075.)

Lindsley, D. B. Attention, consciousness, sleep and wakefulness. In: John Field (ed.) Handbook of Physiology: Sec. I, Neurophysiology, Vol. III, Pp. 1553-1593. Washington, D.C.: Amer. Physiol. Soc., 1960. (See particularly pp. 1575-1589.)

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*1) E. Donchin, J. D. Wicke and D. B. Lindsley, Cortical Evoked Potentials and Perception of Paired Flashes, Science Vol. 141, No. 3857, pages 1285-1286, Sept. 27, 1963

2) Manfred Haider, Paul Spong and Donald B. Lindsley, Attention, Vigilance, and Cortical Evoked-Potentials in Humans, Science Vol. 145, No. 3628, pages 180-182, July 10, 1964

There are of course many psychophysical and behavioral methods for assessing ability to make perceptual discriminations, for studying sequential judgments and adjustments under conditions of rest, alertness, vigilance, and stressful states. I believe that the EEG and the extension of it by means of computer analysis has the potential for providing an index of changes in the brain before these are reflected in behavior and decision processes. However, many of these things are just now being tried out and it is not certain that all of them will be productive in this regard, nor is it certain that all of them may be studied under conditions which might be necessary to simulate orbital flight conditions.

3. Submitted by Adey

It is not clear to me on the basis of the questions that you list at what particular audience your evaluation is aimed, and since this quite critically effects the nature of the reply, I hope you will forgive me for ambiguities that my response may contain. I would doubt whether any appeal to punditry can truly evaluate the use of the EEG in this area. It is only very recently that a few of us have been able to collect records from pilots of high performance aircraft, from freeway drivers and others undergoing environmental stresses similar to those encountered in space flight. As you probably understand, it is only very recently that the requisite technology has been available for collection of the EEG under these circumstances. I point this out in some detail, because our own group is currently evaluating the baseline EEG from 200 astronaut and pilot trainees at the Houston Manned Spacecraft Center. These EEG's have been collected according to a tape recorded protocol and are currently undergoing analysis by complex pattern recognition techniques not previously applied to the EEG. These techniques have been developed in our laboratory. Until these techniques have been applied to an adequate baseline such as the one collected under these rigidly prescribed conditions, there seems little point in hoping that previous baselines collected in a more or less haphazard fashion on a widely varying series of subjects can be appropriately applied to the conditions experienced by an astronaut in actual space flight.

I do not mean to be discouraging, nor do I wish to discount much previous work in clinical EEG laboratories, but the specific nature of the problem and the specific questions that you have asked make it necessary to draw attention to the critical aspects of the problem.

In a specific answer to Question No. 4, my colleagues and I consider that the EEG can provide a highly reliable evaluation of states of alertness, drowsiness and boredom, in incipient sleep and an accurate evaluation of the depth of sleep under conditions of actual space flight. This opinion is based firstly on the feasibility of collection of appropriate EEG records on an essentially "non-interference" basis from man performing pilot functions and other critical activities in the spacecraft operation, as well as during sleep in a relaxed environment. Our studies have established the feasibility of satisfactory data collection from individuals performing comparable tasks, such as piloting high performance aircraft and freeway driving. The analysis techniques that we have applied to the data include auto- and cross-spectral analyses, displayed as contour plots of continuous spectral density analysis and as contours of coherence. The coherence plotting method has proved exquisitively sensitive in revealing changing interrelations in a pattern of scalp recording leads. Equal value attaches to the use of equivalent noise bandwidth-duration stability functions which have been calculated in a variety of states ranging from extreme alertness to deep sleep, and which appear to adequately specify differences between these physiological states in ways not possible from visual inspection of the records. This applies particularly to such states as dream or paradoxical sleep, in which the EEG record closely resembles that of the alerted state. Our studies of depth leads in animals has indicated a feasibility of detecting changes that relate to actual correctness and incorrectness of decision making, but the feasibility of such an approach on scalp leads on man has not yet been proven. However, we have clearly detected states of increased alertness relating to the decision making process in subjects undergoing auditory vigilance tasks, by the use of continuous spectral density plots.

In answer to Question No. 5, it would seem highly undesirable to hinge any physiological monitoring system about a single parameter, even if it be as revealing as the EEG. Much additional information can be gathered from studies of eye movements, electromyographic records from the trunk and neck, the galvanic skin response, heart rate and respiration. However, none of the latter offers the detailed information and accurate correlation with physiological states of alertness and directed attention that can be secured from the EEG. Moreover, only the EEG can reveal the precise nature of normal and abnormal states of unconsciousness, including the depth of the various phases of sleep. The latter would appear a critical requirement in the evaluation of man's adjustment to prolonged space flight, and would determine both optimal sleep-work cycles and man's ability to sustain judgment and high performance level in prolonged space flight.

4. Submitted by Halberg

In keeping with Dr. Barlow's advice* I am indeed interested in uses of the human electroencephalogram in connection with studies of the sleep-wakefulness cycle. A point raised by Dr. Pitts has been the question as to whether the development of the sleep-wakefulness cycle sketched in Figure 14 and analyzed in Figure 15 of the enclosed reprint** (pages 183 and 184 in Halberg, F.: Periodicity analysis--a potential tool for biometeorologists. Int. J. Biometeorology 7: 167-191, 1963) might be reversed in the presence of a reduced input into the reticular formation. The physiologic model for such a reversal has been alluded to in Halberg, F., Halberg, E., Barnum, C. P. and Bittner, J. J.: Physiologic 24-hour periodicity in human beings and mice, the lighting regimen and daily routine. Pages 803-878 in Photoperiodism and Related Phenomena in Plants and Animals, R. B. Withrow, ed. AAAS, 1959. In our laboratory we have already extensive though unpublished evidence for the presence of an ultradian band (frequencies with one cycle in 3-5 hours) as well as of a circadian one in the human electroencephalogram. Accordingly, a study of spectral variance shifts in the frequency analyzed EEG might be a reasonable dividend from monitoring human EEG's during flights in extraterrestrial space. This gauge might be more sensitive when newly developed computer programs are used for the purpose of

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* Quotation from Dr. Barlow's Reply: Another possible use of the EEG for man in space is in connection with the sleep-wakefulness cycle of a subject in an orbiting satellite. I believe that Dr. Franz Halberg, at the University of Minnesota, may have an interest in this latter problem.

**This reprint consisted of 25 pages. For this reason it was not reproduced for inclusion in this report.

frequency analysis in the circadian and ultradian domains of the EEG than the exclusive reliance on high frequency analysis within the Berger range, and certainly both such types of analysis might be added to an examination of EEG's for sleep spindles and the like.

While our laboratory is quite active in terms of experimental designs and computer programs for analyses, we have had no experience with sensors that I understand are now available to others. The availability of the latter and of an appropriate data transfer system will contribute very heavily to any answer to the question whether in 1964 the use of the human EEG for studies in human performance might be utopian or realistic.

I should emphasize also the need for a correlation between variance shifts in the circadian and ultradian domain of electroencephalographic frequencies with performance parameters, such as decision time, in the course of groundwork--before such plans are incorporated into bioastronautic planning. I have only superficial familiarity with decision times evaluated, for instance, by the difference between multiple choice and visual reaction times. Such endpoints and other behavior endpoints will have to be correlated in groundwork with the yield of electroencephalographic analysis before suggesting the use of electroencephalographic endpoints for the purposes of gauging human performance in the overall man-machine system.

D. APPENDIX

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