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PHYSIOLOGICAL RECORDING FROM PILOTS OPERATING AN AIRCRAFT SIMULATOR

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PHYSIOLOGICAL RECORDINGS FROM PILOTS OPERATING AN AIRCRAFT SIMULATOR

CARLTON E. MELTON, JR., Ph. D.

The following quotation is the synopsis of a Civil Aeronautics Board Aircraft Accident Report.[1]

"About 2040, October 30, 1959, Piedmont Airlines Flight 349 crashed on Bucks Elbow Mountain located about 13 miles west of the Charlottesville-Albemarle County, Virginia Airport. The crew of 3 and 23 of 24 passengers were killed; the sole survivor was seriously injured. The aircraft, a DC-3, N-55V, was demolished by impact.

"From the available evidence it is the determination of the Board that this accident occurred during an intended instrument approach. More specifically, it occurred during the inbound portion of the procedure turn which was being flown 8 to 11 miles west of the maneuvering area prescribed by the instrument approach procedure.

"The Board concludes that the lateral error resulted from a navigational omission which took place when the pilot did not turn left about 20 degrees in conformity to V-140 airway at the Casanova omni range station. Consequently, when the pilots believed the flight was over the Rochelle intersection it was in fact 13 miles northwest of that position. As a result of this position, when the pilot turned left and flew the heading normally flown from Rochelle intersection, the path of the aircraft over the ground was displaced 8 to 11 miles west of the prescribed track. The Board further concludes that the error was undetected because tracking and other instrument approach requirements were not followed precisely.

"From information regarding the personal background of [the Captain] and expert medical analysis of this information, it is the Board's opinion that preoccupation resulting from mental stress may have been a contributing factor in the accident cause."

In view of the fact that this air carrier Captain was undergoing psychotherapy and that a part of that therapy had involved the administration of psychopharmacologic agents, the CAB recommended that the FAA initiate exploratory studies to determine how the use of such drugs related to the safety of flight.

The question was referred to the Bureau of Aviation Medicine, Research Requirements Division,* and finally to the Civil Aeromedical Research Institute for consideration. It was quickly appreciated by the researchers at CARI that this was a complex question of more far-reaching significance than providing an explanation of the Piedmont crash.

A committee of CARI senior scientists immediately convened to explore the many aspects of drug usage in Civil Aviation. Federal Aviation Regulations are clear[2] in stating that no person shall fly as pilot or crew member while under the influence of intoxicating liquor or any drug which affects his faculties in any manner contrary to safety. This committee considered many questions relating to drug usage by both ground personnel and flight crews.

However, the committee decided that the most urgent problem was the effects of drugs with central nervous system depressing activity. The rapid burgeoning of tranquilizers reflected their widespread use and it was quickly decided that this drug represented the logical starting point for this investigation. Antihistamines likewise represented one of the most commonly-used drugs and one certainly likely to be used

*Presently, Office of Aviation Medicine, Research and Education Division.

by flyers for symptomatic relief of respiratory passage congestion.

The questions to be answered were reduced to the following: (1) to determine whether or not therapeutic doses of two common drugs, a tranquilizer and an antihistamine, cause decrements in the operating proficiency of pilots, and (2) do those drugs when given in therapeutic doses have measureable effects on selected physiological functions? This report deals with the recording and interpretation of physiological data obtained from drug-treated pilots operating a C-97 simulator.

METHODS

Six volunteer subjects were studied in this preliminary investigation. They ranged in age from 37 to 42 years. All six subjects were highly experienced (8,000 – 16,000 hours) multiengine pilots; five were FAA Flight Inspectors and one was an FAA Air Carrier Inspector. None of the subjects was familiar with the operation of the C-97 aircraft.

Each subject was assigned to CARI for two weeks. His schedule for that period is shown in Table I. His daily schedule is shown in Table II, with the exception of the first day which was devoted to orientation and medical examination.

All of the subjects were in good health and were not at the time of experimentation taking any drugs, nor had they knowingly in the past taken either of the drugs to be tested.

The two drugs chosen for assay were meprobamate (2-Methyl-2-propyl-1, 3-propanediol dicarbamate),† a tranquilizer, and chlorpheniramine (2-[p-chloro-α-(2-dimethylamino-ethyl) benzyl]pyridine),‡ an antihistamine. Meprobamate was given 400 mg q.i.d. and chlorpheniramine 4 mg q.i.d. according to the schedule in Table I. The study was carried out under double-blind conditions; all drugs and placebos were given in identical capsules and care was taken not to suggest to the subjects what the possible effects might be. Table III shows the distribution of the two drugs among the six subjects. Each subject got only one of the two drugs.

Upon arrival at the simulator each subject took a battery of psychological tests. He was then weighed and determinations were made of his oral temperature, radial pulse rate, respiratory rate and blood pressure. Each subject was then fitted with sensors to yield seven channels of physiological information: (1) electrocardiogram, (2) heartrate, (3) respiratory rate, (4) skin resistance, (5) electroencephalogram (frontal-central), (6) electroencephalogram (parietal-occipital), (7) electro-oculogram.

Electrocardiogram: The skin of a small area of the lateral chest wall was cleaned with alcohol. Electrocardiograph paste was then massaged into the prepared site and conventional rectangular silver limb lead electrodes were fastened in place with a rubber strap passed around the chest. A ground electrode was located on the forehead between the eyes. Connections to the electrodes were made with #18 plastic-coated stranded copper wires, which were brought up the subject's back and taped into place. The wires terminated in a miniature 14-prong connector (USC M1-14 HR). Wires from the mating connector were passed behind the padding of the overhead of the simulator and connected to the input terminal binding posts of a Grass shielded input cable. The cable was passed out through the front of the simulator and was connected to the input of a Grass EKG plug-in preamplifier. The preamplifier was fitted into a D.C. driver amplifier and power supply of a Grass 4-channel Polygraph (Machine I). The contour of the electrocardiogram corresponded to Standard Lead I and was recorded at a paper speed of 5 mm/sec on Channel 1 of Machine I (Fig. 1). This measurement was made primarily as a validity check on the heartrate record.

Heartrate: The R wave of the EKG was used to trigger a Grass cardiotachometer preamplifier. The heartrate was recorded on Channel 2 of Machine I (Fig. 1). The cardiotachometer

† Placidon, Nervonus, Cirpon, Perequil, Calmiren, Ecuanil, Mepavlon, Equanil, Miltown, Mepantin, Biobamat, Panediol, Pertranquil, Perquietil, Harmonin, Quanil, Probamyl, Oasil, Cyrpon, Sedazil, Apascil, Atraxin, Urbil, Meprosin.[5]

‡ Chlor-Trimeton, Allergican, Piriton.[5]

TABLE I. EXPERIMENTAL PROTOCOL*

Day No.	Weekday	Activity A.M.	Activity P.M.	Remarks
1	Mon.	Orientation Medical Exam	Simulator Training	No recording No drugs
2	Tue.	Simulator Training	Testing at CARI	1st recording No drugs
3	Wed.	Simulator Training	Testing at CARI	2nd recording No drugs
4	Thur.	Simulator Experimental	Testing at CARI	3rd recording No drugs
5	Fri.	Simulator Experimental	Testing at CARI	4th recording No drugs
6	Sat.	No testing	No testing	Placebo
7	Sun.	No testing	No testing	Drug
8	Mon.	Simulator Experimental	Testing at CARI	5th recording Drug
9	Tue.	Simulator Experimental	Testing at CARI	6th recording Drug
10	Wed.	Simulator Experimental	Testing at CARI	7th recording Drug
11	Thur.	Simulator Experimental	Testing at CARI	8th recording No drugs
12	Fri.	Simulator Experimental	Testing at CARI	9th recording No drugs
13	Sat.	Simulator Experimental	Testing at CARI	10th recording Placebo

*Medical examinations were performed by Samuel F. Flynn, M.D., Clinical Examinations Branch, Clinical Services Division, FAA; drug dosage schedule was established by Richard W. Payne, M.D., Department of Pharmacology, Oklahoma University Medical Center. Experimental protocol was worked out by a committee of CARI scientists consisting of Dr. George T. Hauty, Acting Director and Chief, Psychology Branch; Dr. P. F. Iampietro, Chief, Environmental Physiology Branch and Project Director; Dr. Bruno Balke, Chief, Biodynamics Branch; Dr. Paul W. Smith, Chief Pharmacology-Biochemistry Branch; Dr. P. C. Tang, Chief, Neurophysiology Branch; Dr. David K. Trites, Chief, Selection Section, Psychology Branch; Dr. William F. O'Connor, Research Psychologist; and Dr. C. E. Melton, Chief, Electrophysiology Section, Neurophysiology Branch.

TABLE II. DAILY SCHEDULE FOR DAYS 2-10

Time	Activity
0630	Arise
0730	Arrive at simulator
0730-0800	Psychological testing
0800-0830	Preparation for flight
0830-0845	Physiological testing
0845-1245	Flight
1245-1315	Psychological testing
1315-1400	Lunch
1430-1630	Other testing at CARI

TABLE III. DISTRIBUTION OF MEPROBAMATE AND CHLORPHENIRAMINE AMONG THE SIX SUBJECTS

		Simulator	Subject No.					
Weekday	Day No.	Run No.	1	2	3	4	5	6
Mon	1		0	0	0	0	0	0
Tue	2	1	0	0	0	0	0	0
Wed	3	2	0	0	0	0	0	0
Thur	4	3	0	0	0	0	0	0
Fri	5	4	0	0	0	0	0	0
Sat	6		P1*	P1	P1	P1	P1	P1
Sun	7		M†	C‡	M	C	M	C
Mon	8	5	M	C	M	C	M	C
Tue	9	6	M	C	M	C	M	C
Wed	10	7	M	C	M	C	M	C
Thur	11	8	0	0	0	0	0	0
Fri	12	9	0	0	0	0	0	0
Sat	13	10	P1	P1	P1	P1	P1	P1

* Placebo (Lactose)

† Meprobamate, 400 mg q.i.d.

‡ Chlorpheniramine, 4 mg q.i.d.

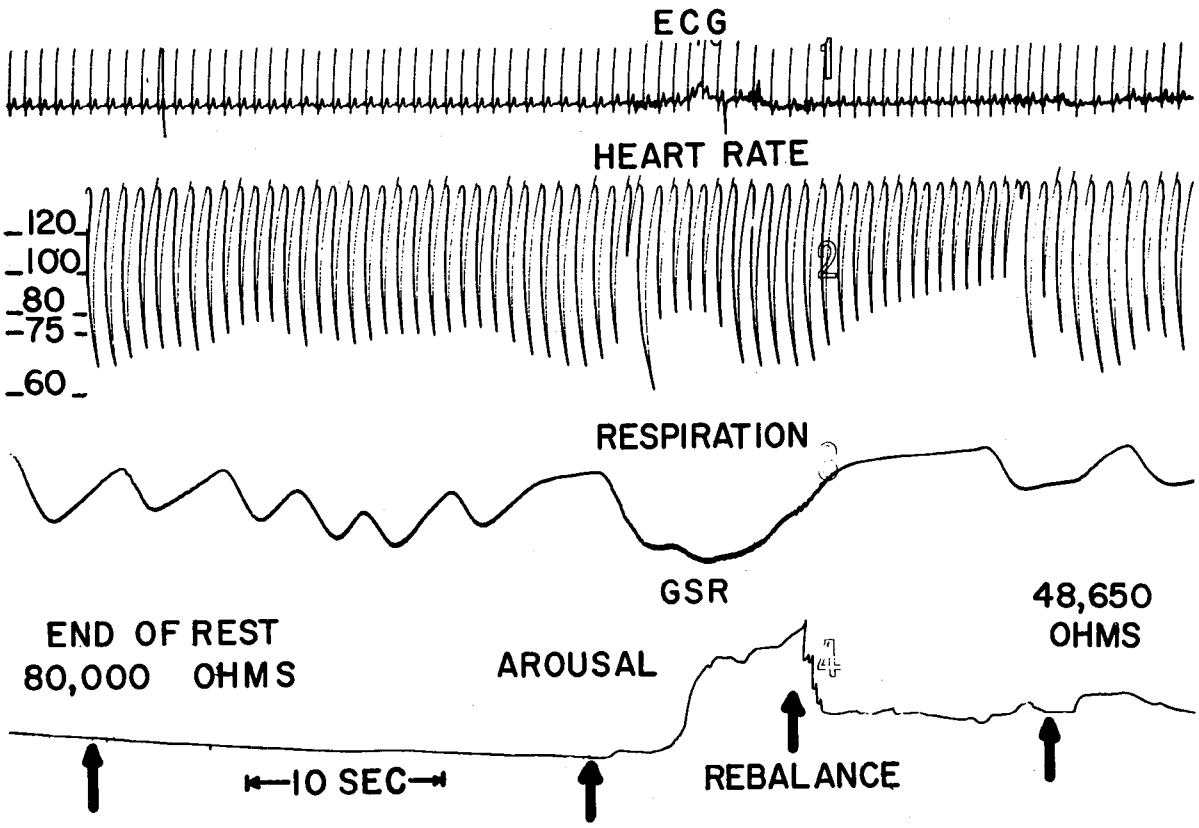

FIGURE 1: Record from Machine I.

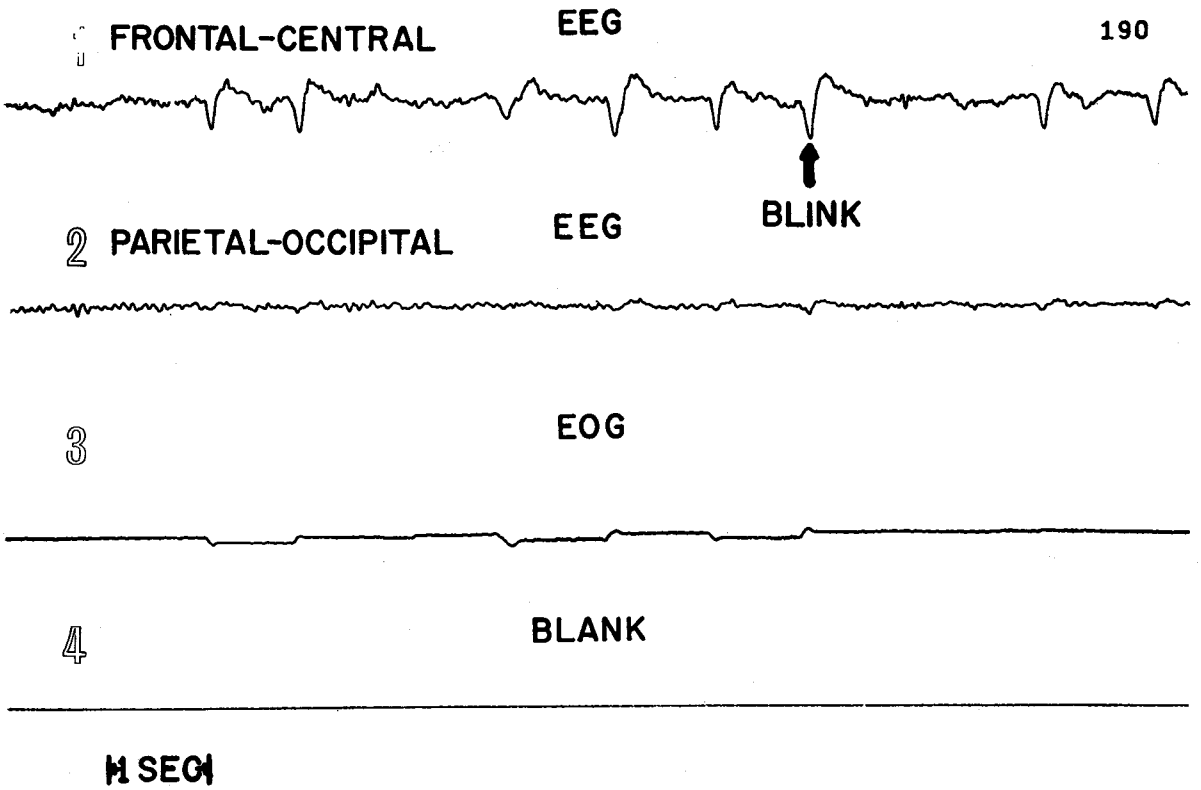

FIGURE 2. Record from Machine II.

was calibrated to record heartrates between the limits of 60 bpm and 120 bpm. The length of the deflection is inversely related to the heartrate; i.e., directly related to the interval between two successive R waves. The triggering R wave was obtained by simply wiring across from the EKG binding posts to the cardiotachometer binding posts.

Respiratory rate: Two different methods were tested for obtaining respiratory rate, (1) the Yellow Springs Instrument Company Pneumograph operated with a Pneumograph Amplifier and (2) a Yellow Springs thermistor probe (#812) inserted about 3/4 inch in the left nostril. The probe was connected to a Yellow Springs Telethermometer. Both the Pneumograph Amplifier output and the Telethermometer output were connected directly to a third Grass input terminal, the cable from which led to the input of a Grass Low-Level preamplifier operated in the D.C. mode with 20K input resistance. The first method proved unsatisfactory because of the extreme lability under these experimental conditions of the mercury-filled pneumograph tube. The walls of the tube, made of siliconized rubber, admitted minute quantities of air which resulted in separation of the mercury column. The second method proved adequate for the purpose of the experiment. As air was inspired the thermistor was cooled thereby changing its resistance and unbalancing the Telethermometer bridge circuit and thus producing a writing pen deflection. The polarity of the input was selected so that inspiration of air resulted in an upward deflection of the pen (Channel 3 of Machine I, Fig. 1).

Galvanic Skin Response (GSR): The measurement of this function, also known as the psychogalvanic response (PGR), required no instrumentation other than the Grass Low Level preamplifier, Model 5P1, which has a PGR position on the input mode selector. When the instrument is properly calibrated the amplifier balance controls read directly in ohms. The skin resistance was determined simply by balancing the amplifier so that the pen rested on the baseline. Changes in GSR could be read without rebalancing directly from the paper chart within the limits of resistance represented by the chart width (Channel 4, Machine I, Fig. 1).

The sensor for this function was a disc-type silver electroencephalograph electrode. Several locations of attachment were tested—forehead, palm of the hand, sole of the foot and nape of the neck. Of these locations only the palms of the hands and the soles of the feet were found to respond well enough for the purposes of these experiments to startling stimuli (loud noises or slaps) or to embarrassing accusations. However, it was soon found that the use of the hands and feet in controlling the simulator produced movement artifacts. Further experimentation revealed that the heel of the palm of the left hand was responsive enough to reveal changes in skin resistance and that such measurements were not affected by the normal movements involved in control of the simulator. The skin of that area was cleaned with alcohol, the electrode together with its wire lead was passed through the left sleeve of the subject's shirt, attached with Bentonite electrode paste to the heel of the palm of the left hand and taped firmly in position (Fig. 3). The wire lead from the electrode was attached to the previously-mentioned miniature plug. The ground reference connection for this measurement was located on the forehead symmetrically between the eyes and served as a ground for the electro-oculogram and electrocardiogram as well as GSR.

Unsuccessful attempts were made to record changes in skin potential by means of a needle electrode inserted into the earlobe. A Keithley Model 603 electrometer input d.c. amplifier was used in those experiments.

Electroencephalograms (EEG): Two channels of bipolar EEG were recorded, frontal-central and parietal-occipital. Sensors were conventional silver disc electrodes attached to the scalp with Bentonite electrode paste and secured with plastic tape. The wires from the electrodes were taped to a welder's headstrap assembly from which the eye shield had been removed (Fig. 3). The lead wires terminated in the miniature 14-prong connector. Wires from the mating connector were passed to the

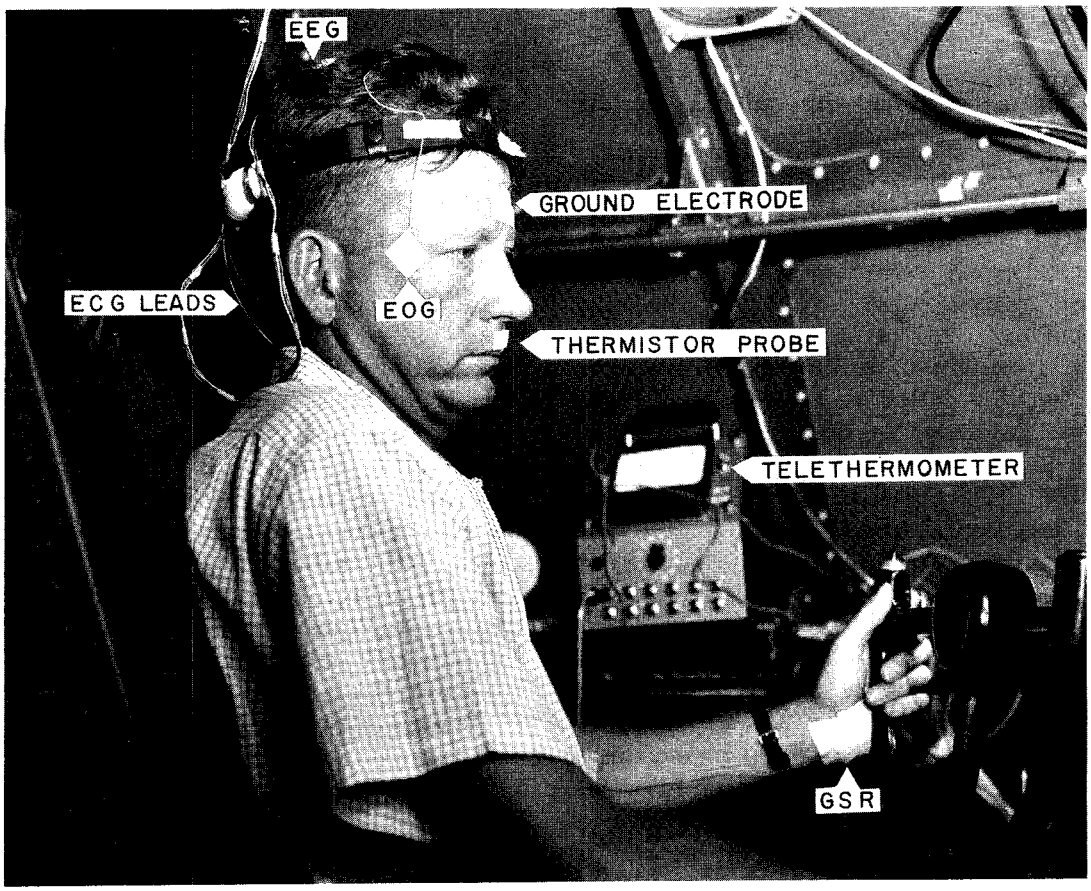

FIGURE 3. Subject seated in simulator.

terminals of two Grass input cables which, in turn, connected to the inputs of Grass Model 5P5C EEG preamplifiers. Records were taken on Channel 1 (frontal-central) and Channel 2 (parietal-occipital) of Machine II at a paper speed of 25 mm/sec (Fig. 2).

Electro-oculogram (EOG): Lateral eye movements were detected with EEG electrodes attached to the outer canthi of the eyes in a manner identical to the attachment of scalp electrodes (Fig. 3). The previously-mentioned ground electrode situated on the forehead was the reference. Changes in the geometry of the corneo-retinal potential produced by lateral eye movements were detected at the electrode site. Lead wires from the electrodes were fixed to the headstrap assembly and terminated in the 14-prong connector. Input was via a Grass shielded cable to a Grass Low-Level preamplifier, Model 5P1, operated in the D.C. mode. Input polarity was arranged so that a look to the right was registered as a downward deflection and a look to the left as an upward deflection (Channel 3, Machine II, Fig. 2). Since the subjects operated the simulator from the left seat, most of the time the gaze was directed either straight ahead or to the right.

These six sets of sensors were attached to the subjects outside the simulator. Lead wires from the EKG-heartrate, GSR, EEG and EOG electrodes were pig-tailed to the 14-prong miniature connector and the respiration lead terminated in a phone plug. When the subject was seated in the simulator the 14-prong connector was joined to its mating connector and the thermistor probe was plugged into the Telethermometer (Fig. 3). The subjects were in two-way voice contact with one of the investigators inside the simulator who monitored the track of the flight and gave maneuvering instructions. The subjects received instructions from a speaker located on the left side of the cockpit and spoke into a conventional hand microphone which was connected to the investigator's headset. The investigator outside the simulator had a speaker over which he could hear both the subject and the investigator inside the simulator. A television camera was set up on the right side of the cockpit; each of the investigators had a receiver so that the pilot

was under constant visual observation via closed-circuit TV.

After he was seated in the simulator the subject was instructed to lean back comfortably, refrain from smoking and rest for 15 minutes. The physiological measurements made during this rest period were taken as baseline measurements.

At the termination of the rest period, the subject began a series of 10 simulated flight maneuvers consisting of precision turns, some of which involved precise gain and loss of altitude. The "flight" lasted about 2 1/2 hours and was terminated with an Instrument Landing System approach and landing. The subject then took another 5 minute rest period after which he left the simulator. Post-flight determinations were made of his oral temperature, pulse rate, respiratory rate and blood pressure.

During each of the 2 to 3 hour "flights," 1000 to 1250 feet of physiological recordings were obtained. The seven channels of information, each of which was at least 1000 feet in length, constituted over a mile of record for each flight. It was obviously impossible to reduce all of the data on each record; therefore, a time sampling technique was developed so that about 1/3 of the record taken during each flight maneuver was analyzed. The measurements taken were of heartrate, respiratory rate, skin resistance, blink rate and lateral eye movements. Mean values, their deviations and ranges, were recorded in chart form. The electroencephalograms were not subjected to critical analysis because of interfering muscle potentials during activity. These tracings will be considered in conjunction with a subsequent CARI Report dealing with the clinical electroencephalographic records of these pilots.

RESULTS AND DISCUSSION

There was no difference in the mean values for blink rate, lateral eye movements, heartrate and respiratory rate on and off of drug treatment. The skin resistance was higher during rest on the days when a drug was given than on days when no drug was given. The skin resistance after the subject was aroused, however, fell to the same level regardless of treatment (Figs. 4-8). The pre- and post-flight values of oral temperature, blood pressure and respiratory rate were not different, nor were they consistently different on drug and non-drug days.

These results can simply be summarized by saying that neither of the drugs used had any effect on the physiological parameters measured under these experimental conditions. Several reasons for the essentially negative nature of these results are apparent. This population of subjects, healthy pilots, did not represent the problem population, emotionally disturbed or allergic pilots. The doses used were recommended for relief of specific disease states; if the subject population had been suffering from conditions for which these drugs might ordinarily be prescribed, there might have been a measureable normalizing effect. However, the amount of these drugs necessary to depress normal function must be considerably greater than the therapeutic dose.

It has been found in other studies involving the operation of automobile simulators by normal subjects that twice the usual therapeutic amount of meprobamate given as a single dose had no identifiable behavioral toxicity.[4] Those investigators found, however, that sweating was significantly increased.

It is probably unnecessary to point out that the negative findings in this preliminary or feasibility study are not to be interpreted as expressing or implying that tranquilizers or antihistamines can safely be used in the actual flight situation. Some of the reasons why such a conclusion is not allowable are listed as follows:

1. None of the subjects in this study was hyper-reactive to the drugs tested; a larger population might reveal exaggerated responses by some people.

2. Use of a simulator closely replicates many features of actual flight but the effects of altitude and acceleration are lacking.

3. The drugs may have had effects on functions not measured, for example, depth perception, and other visual functions.

4. Responses to truly dangerous situations could not be evaluated.

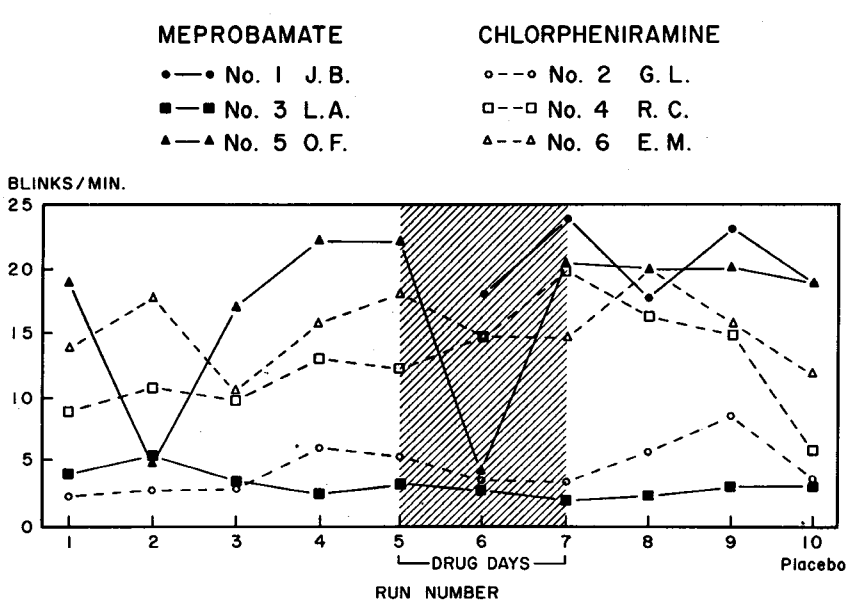

FIGURE 4. Average rate of blinking for each subject during each simulated flight. Subject No. 5 showed a depression of blink rate on the second day of meprobamate treatment, but high rates on the first and third days of drug intake. This subject also showed a depressed blink rate during flight No. 2 when no drug was given.

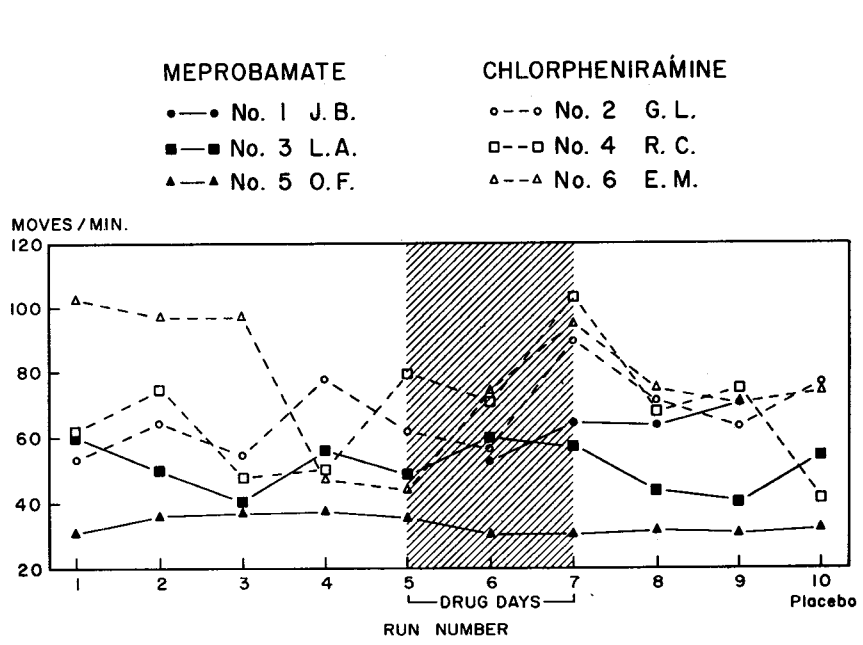

FIGURE 5. Frequency of lateral eye movements by each subject on each simulated flight.

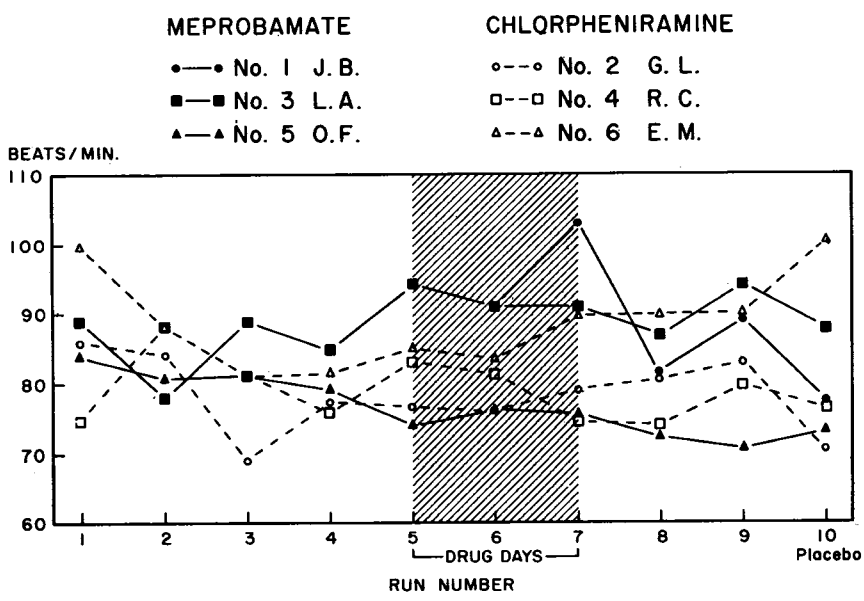

FIGURE 6. Average heartrate for each subject during each simulated flight.

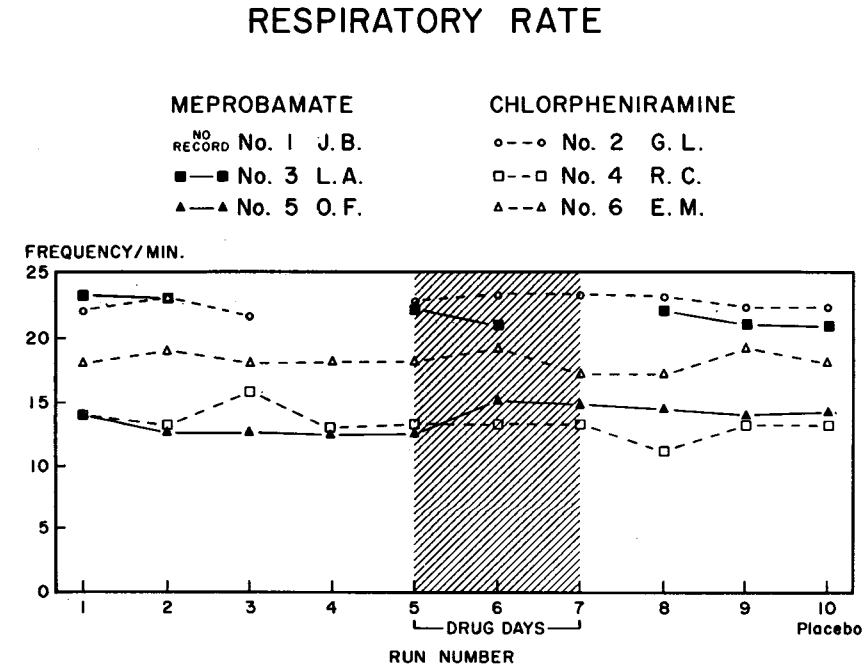

FIGURE 7. Average respiratory rate for subjects 2-6 during each simulated flight. No record was obtained from subject No. 1.

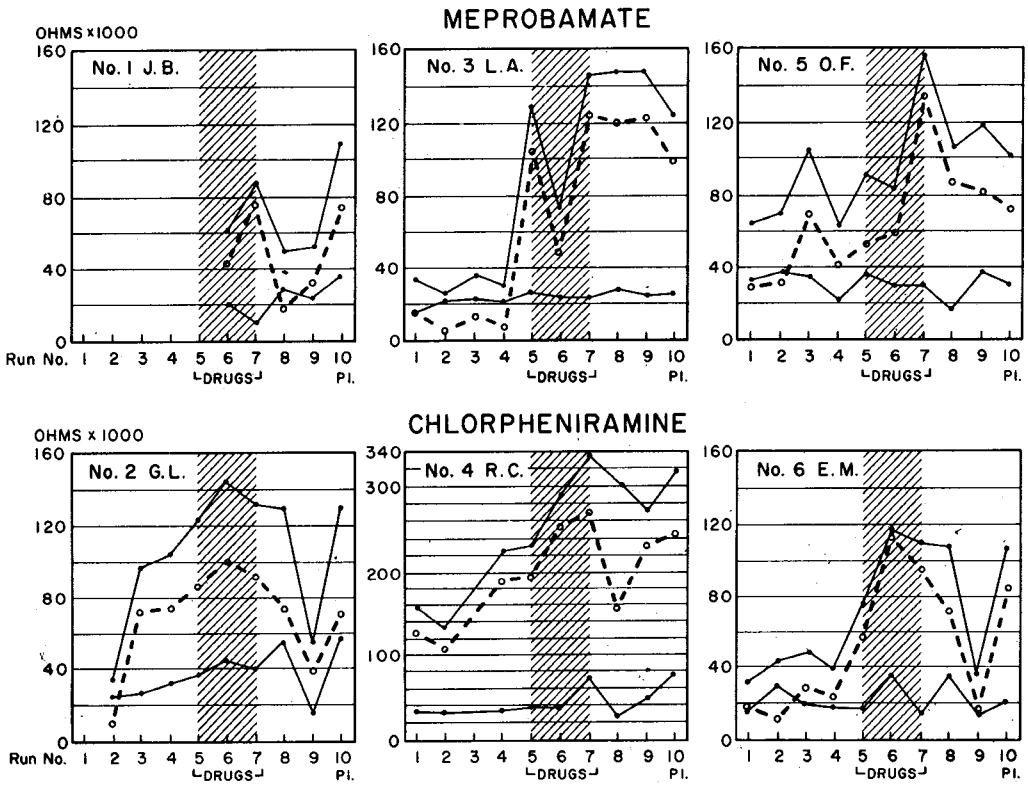

FIGURE 8. Amplitude of change in GSR (dashed line) and range of values (upper and lower lines) for each subject during each simulated flight. On each day the highest skin resistance was reached during the pre-flight rest period.

5. Long-term effects of the drugs could not be evaluated.

These data do not, therefore, indicate any alteration of the recommendation that flight activities be suspended for 24 hours after ingestion of the standard dose of either meprobamate or chlorpheniramine.[3]

From a positive point of view, this study shows the feasibility of obtaining reliable interpretable physiological records from subjects in the work situation. The sensitivity of the GSR recording was particularly gratifying since it was possible in some subjects to anticipate action by the drop in skin resistance before any overt movement was made.

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