NATIONAL RESEARCH COUNCIL

DIVISION OF MEDICAL SCIENCES

COMMITTEE ON

AVIATION MEDICINE

Conference on Fatigue

21 June 1948
Washington, D. C.

NATIONAL RESEARCH COUNCIL, DIVISION OF MEDICAL SCIENCES

2101 Constitution Avenue, Washington, D. C.

COMMITTEE ON AVIATION MEDICINE

Conference on Fatigue

21 June 1948 - 10:00 A. M.

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NATIONAL RESEARCH COUNCIL

Division of Medical Sciences

Conference on Fatigue

The conference, held under the auspices of the Committee on Aviation Medicine, convened at 10:00 A.M., on 21 June 1948, in the National Academy of Sciences - National Research Council Building, 2101 Constitution Avenue, Washington 25, D. C.

Attendance:

For the Committee:

Dr. Detlev W. Bronk, Chairman
Dr. E. J. Baldes
Dr. Eugene F. DuBois
Dr. Wallace O. Fenn
Dr. John C. Flanagan
Dr. H. K. Hartline
Dr. A. C. Ivy
Dr. Charles E. Kossmann
Dr. Joseph L. Lilienthal, Jr.
Dr. George L. Maison
Dr. Craig L. Taylor

For the National Research Council:

Mr. H. N. Gardner
Dr. Joseph Ney
Dr. Hayden C. Nicholson
Dr. Malcolm Ray
Dr. Lewis H. Weed
Dr. Herman S. Wigodsky
Dr. Raymund L. Zwemer

For the U. S. Army:

Lt. Col. Wate W. Abbott, 4th Fighter Group, Andrews Air Force Base, Washington, D. C.
Brig. General Harry G. Armstrong, Randolph Air Force Base, San Antonio, Texas
Dr. A. Bingel, Randolph Air Force Base, San Antonio, Texas
Dr. S. Gerathewald, Randolph Air Force Base, San Antonio, Texas
Capt. Elizabeth Guild, Randolph Air Force Base, San Antonio, Texas
Dr. J. W. Heim, Aero Medical Laboratory, Wright-Patterson Air Force Base, Dayton
Col. William J. Kennard, Air Surgeon's Office, Hdqrs. USAF, Washington, D. C.
Lt. Col. E. C. Lentz, Air Surgeon's Office, Hdqrs. USAF, Washington, D. C.
Dr. W. Noell, Randolph Air Force Base, San Antonio, Texas
Dr. J. Prast, Randolph Air Force Base, San Antonio, Texas

For the U. S. Army (Cont'd):

Lt. Col. B. S. Preston, 4th Fighter Group, Andrews Air Force Base, Washington, D. C.
Lt. George E. Schafer, 4th Fighter Group, Andrews Air Force Base, Washington, D. C.
Col. William S. Stone, Surgeon General's Office, Washington, D. C.
Dr. J. Tonndorf, Randolph Air Force Base, San Antonio, Texas

For the U. S. Navy:

Lt. Comdr. G. W. Anderson, CNO - OP55T, Navy Dept., Washington, D. C.
Mr. Harry G. Bartlett, Jr., BuAer, Navy Dept.
Comdr. L. S. Beals, Jr., Special Devices Center, Port Washington, O.N.R. Long Island, N.Y.
Lt. Edward L. Beckman, School of Aviation Medicine & Research, Pensacola
Mr. C. S. Bridgman, Special Devices Center, O.N.R., Port Washington, Long Island, N.Y.
Lt. Comdr. R. L. Christy, BuMed & Surgery, Navy Dept., Washington, D. C.
Capt. W. Dana, Research Div., BuMed & Surgery, Navy Dept.
Mr. G. C. Danch, BuAer, Fighter Design Branch, Navy Dept.
Comdr. Jack W. Dunlap, BuMed & Surgery, Navy Dept., Washington, D. C.
Lt. Paul C. Durup, BuAer, Navy Dept., Washington, D. C.
Capt. J. C. Early, BuMed & Surgery, Navy Dept., Washington, D. C.
Dr. A. C. Flackbert, Special Devices Center, O.N.R., Port Washington, Long Island, N.Y.
Dr. James George, BuAer, Navy Dept., Washington, D. C.
Rear Adm. B. Groesbeck, Chief, Division of Aviation Medicine, Navy Dept.
Lt. Comdr. W. R. Hazlett, Office of Naval Research, Washington, D. C.
Miss B. Hulfish, Office of Naval Research, Physiology Branch, Washington, D. C.
Dr. E. A. Jerome, Naval Medical Center, Bethesda, Maryland
Lt. W. L. Jones, DCNO (Air) Navy Dept., Washington, D. C.
Capt. Wilbur E. Kellum, Naval Air Station, Pensacola
Dr. David M. Klein, Naval Medical Research Institute, Bethesda, Md.
Dr. Charles Lightfoot, School of Aviation Medicine, NAS, Pensacola
Rear Adm. T. C. Lonnquest, BuAer, Navy Dept., Washington, D. C.
Dr. J. W. MacMillan, Office of Naval Research, Washington, D. C.
Dr. M. T. McCown, BuAer, Navy Dept., Washington, D. C.
Dr. E. S. Mendelson, Air Materiel Equip. Lab., Naval Air Experimental Station, Philadelphia
Comdr. A. B. Metsger, BuAer, Navy Dept., Washington, D. C.
Dr. J. M. Pasternack, Office of Naval Research, Washington, D. C.
Mr. J. N. Pecoraro, Special Devices Center, O.N.R., Sands Point, Port Washington, Long Island, N.Y.
Capt. J. R. Poppen, Air Materiel Equip. Lab., Naval Air Experimental Station, Philadelphia
Comdr. ReJose, CNR (Air) Navy Dept.
Dr. Orr E. Reynolds, Office of Naval Research, Physiology Branch, Washington, D. C.
Comdr. James F. Rigg, DCNO (Air) Navy Dept., Washington, D. C.
Dr. Robert H. Shatz, Office of Naval Research, Washington, D. C.
Dr. M. C. Shelesnyak, Office of Naval Research, Washington, D. C.

For the U. S. Navy (Cont'd):

Capt. C. W. Shilling, Office of Naval Research, Washington, D. C.
Comdr. H. A. Smedal, Research Division, BuMed & Surgery, Navy Dept., Washington, D. C.
Dr. H. Sontag, BuAer, Navy Dept., Washington, D. C.
Lt. Comdr. Irving R. Stone, Naval Medical Research Institute, Bethesda, Md.
Dr. R. Thauer, Air Materiel Equip. Lab., Naval Air Experimental Station, Philadelphia
Lt. Comdr. R. J. Trauger, BuAer, Navy Dept., Washington, D. C.
Dr. S. D. Van Court, Office of Naval Research
Comdr. A. P. Webster, BuMed & Surgery, Navy Dept., Washington, D. C.
Dr. R. J. Willingham, BuAer, Navy Dept., Washington, D. C.
Lt. Comdr. Edward M. Wurzel, Naval Medical Research Institute, Bethesda, Md.
Dr. J. Yaberman, O.N.R., Sands Point, Post Washington, Long Island, N.Y.

For the National Institute of Health:

Dr. Heinz Specht

For the Civil Aeronautics Administration:

Dr. Dean R. Brimhall
Dr. Barry G. King
Miss Dorothy J. Morrow
Dr. W. R. Stovall

For England:

Surgeon Captain R. A. Graff
Wing Comdr. J. H. Neal
Dr. N. H. Mackworth

Others attending:

Dr. Stanley Baker, Catholic University, Washington, D. C.
Dr. J. E. Barmack, Psychological Corporation, New York, N.Y.
Dr. Carl A. Bollinger, Republic Aviation Corp., Farmingdale, N.Y.
Dr. Harold R. Bohlman, Medical Arts Building, Baltimore, Md.
Dr. Loren D. Carlson, University of Washington, School of Medicine, Seattle
Dr. Francis P. Chinard, Rockefeller Institute, New York, N.Y.
Dr. John D. Coakley, New York City
Dr. D. E. Copeland, Brown University, Providence, R.I.
Dr. Edward L. Corey, University of Virginia Medical School, Charlottesville, Va.
Dr. Emerson Day, Cornell University Medical College, New York, N.Y.
Dr. J. N. Dent, University of Pittsburgh, Pittsburgh, Pa.
Dr. David B. Dill, Army Chemical Center, Edgewood, Maryland
Dr. Paul Fitts, Aero Medical Laboratory, Wright-Patterson Air Force Base, Dayton
Dr. C. C. Furnas, Cornell Aeronautical Laboratory, Buffalo, N.Y.
Dr. Samuel Gelfan, Yale Medical School, New Haven, Conn.

Others attending (Cont'd):

Dr. C. L. Gemmill, University of Virginia, Charlottesville, Va.
Dr. D. W. Gressly, 201 Wilson Avenue, Beaver, Pa.
Dr. Mason Guest, Wayne University, College of Medicine, Detroit, Mich.
Dr. F. G. Hall, Duke University, Durham, N.C.
Dr. Hudson Hoagland, Worcester Foundation, Shrewsbury, Mass.
Dr. E. C. Hoff, Medical College of Virginia, Richmond, Va.
Dr. C. S. Houston, Exeter, N. H.
Dr. John L. Kennedy, Tufts College, Medford, Mass.
Mr. R. W. Kluge, Cornell Aeronautical Laboratory, Buffalo, N.Y.
Dr. Lloyd Law, National Cancer Institute, Bethesda, Md.
Dr. Charles F. Lombard, University of Southern California, Los Angeles, California
Mr. R. Vincent Lynch, Chance Vought Aircraft, Stratford, Conn.
Dr. C. A. Maaske, University of Colorado Medical Center, Denver, Colorado
Dr. Ross MacCardle, National Cancer Institute, Bethesda, Md.
Dr. C. G. MacKenzie, Cornell University Medical College, N.Y.
Dr. Richard L. Masland, Bowman Gray School of Medicine, Winston Salem, N.C.
Dr. John A. Mathis, Pinckneyville, Illinois
Dr. David K. Morrison, Flight Safety Fdn., 165 E. 72nd Street, New York, N.Y.
Dr. E. S. Nasset, University of Rochester, Rochester, N.Y.
Mr. J. Orlansky, Psychological Corp., New York, N.Y.
Mr. O. E. Pappas, Republic Aviation Corp., Farmingdale, N.Y.
Dr. J. R. Pappenheimer, Harvard Medical School, Boston, Mass.
Dr. F. E. Poole, Lockheed Aircraft Corp., Burbank, California
Dr. Richard L. Riley, Chest Service, Bellevue Hospital, New York, N.Y.
Dr. M. B. Sanders, American Embassy, Paris
Dr. Carl. F. Schmidt, University of Pennsylvania Medical School, Philadelphia
Dr. Henry A. Schroeder, Barnes Hospital, St. Louis, Missouri
Dr. H. C. Shands, Massachusetts General Hospital, Boston, Mass.
Dr. W. G. Smillie, Cornell University Medical College, New York, N.Y.
Dr. J. J. Smith, 706 South Wolcott Avenue, Chicago, Illinois
Dr. P. K. Smith, George Washington University, Washington, D. C.
Dr. Asher Treat, The City College, Dept. of Biology, New York 31, N.Y.
Dr. Morris S. Viteles, University of Pennsylvania, 106 College Hall, Philadelphia

Introduction - Dr. Detlev W. Bronk

It is not necessary to remind this group that the function of the Committee on Aviation Medicine is the furtherance of research in human flight. It also hopes to assist those in the services concerned with aviation medicine and keep civilian scientists informed. It has been a tradition to bring together each year those in the Air Force, Army, and Navy, physiologists and physicians who have retained an active interest in this phase of the service. We hope to keep you informed of what is going on. It would be surprising if we do not have continually recurring problems of a physiological nature. The present program includes new problems on the engineering side as well as the old problems of anoxia, aeroembolism and fatigue. In the last war physiologists thought they would have to do something about fatigue. We did not know how to approach this broad problem but it was one of very acute significance. 1. The services were asked what questions should be considered at this meeting. No problem was thought to be more important than fatigue. We do not mean muscular fatigue primarily but there is no sharp distinction between mental and physiological fatigue. When we looked for a leader for this discussion we thought first of Dr. Fenn who has had much experience in working with muscular fatigue; I hope that we can think jointly about this problem. We should consider what can be done in research and in translating existing knowledge into practical applications. It was a difficult problem during the war to determine how much of the behavior of air crew men was due to military disciplines and was a subject of concern to the flight surgeons. I hope that we can summarize our present knowledge in this area for the benefit of the services and also point out what might be profitable research on this subject.

The Problem of Fatigue - Dr. Wallace O. Fenn

The problem of flyers fatigue is an elusive one and much rhetoric has been expended in an effort to define the term. There are others present much more competent to discuss the problem than myself. I could hardly do better than to read you verbatim General Armstrong's chapter on "Emotional Reactions to Flight" in his classical monograph on Aviation Medicine. In this chapter he writes, "The term fatigue is an inexact expression used to describe either a feeling of weariness or a diminished capacity for doing work, or both, generally as a result of previous activity. However, even in the absence of previous work, fatigue may be complained of, proving that it may arise from purely psychic or emotional stresses." This is as good a definition as could be desired.

In a recent book Bartley and Chute* have discussed the problem at some length. They would limit the word to a very general phenomenon or state of mind and would distinguish it sharply from impairment in the performance of some tissue or the impairment of the performance of the individual at some specific task. From this point of view there may be fatigue without impairment and impairment without fatigue. We can agree at least that fatigue is a complex affair and may be present without any measurable deficiency in the specific task selected for test. Whether there is any important gain in denying the application of the term to conditions in which performance is impaired seems to me very doubtful. This is only another way of saying that one is not

*Fatigue and Impairment in Man. S. H. Bartley and E. Chute, McGraw Hill, N.Y. 1947.

fatigued unless he feels fatigued. I am not inclined however, to haggle over terminology and I propose to discuss the phenomenon and leave the definition to others.

What then is the importance of fatigue and what shall we do about it? How shall we formulate a research program in this difficult field? As a guide to our discussion let me propose the equation that Flyers Fatigue $= \sum$ all the strains

and further

$\sum \text{stresses} = K\,(\sum \text{compensation} + \sum \text{strains})$

In physics, let me remind you, the stress is the force applied and the strain is the change or the deformation which results. The compensations are analagous to heat changes which tend to minimize the stress. Thus if the stress of added heat is applied to ice, the strain which results is a melting of the ice and the compensation is the latent heat of melting ice which tends to maintain the status quo as to temperature. According to the thermodynamic principle of Le Chatelier any stress or change enforced upon a physicochemical system elicits a response that tends to eliminate or to minimize the changes. Some compensation is therefore a thermodynamic expectation. Without pushing this analogy too far let us turn our attention to the significance of the equation for our problem.

The stresses, compensations and strains concerned in this study are of many kinds and may appear in any organ or tissue of the body. The task in any investigation of this sort will be to assay and quantitate the relative importance of the different stresses and their corresponding compensations and strains in the total picture. It is probably unprofitable to try to discriminate between brain and soma, or mind and body in this effort. The organism is a single whole and functions and fatigues as such. Fatigue of one part affects other parts either directly or indirectly through hormones or nervous connections or otherwise. Just as the U.S.A. is no longer able to stand aloof from the world in splendid isolationism so no single part of the body can function by itself. If one country is out of step the program of the world is shattered. If one organ is fatigued the whole body is fatigued. Conversely if the world is sick so is every country in the world. No effect results from a single cause. No cause has a single effect. And every effect is itself the cause of another effect. Affects have effects and effects have affects in endless cycles.

Biological philosophers have recently been employing the reverberating chains of neurones, a concept introduced into physiology by Lorente de No, to explain the basis of memory, of purposeful action, of choice of two alternatives, of teleological development etc. So long as a chain reverberates the fact which it represents is "remembered". (Northrup, Science, April 1948). Behaviour depends then not on simple reflex activity but on modulation by appropriate stimulus of the activity of reverberating chains of neurones. In returning to the point of origin in these circuits of neurones the impulses may have different effects, reenforcing or diminishing, exciting or inhibiting the initial stimulus. This is spoken of as positive or negative feed back. Extending and perhaps modifying this concept slightly for our present purposes we might say that compensations represent positive, and strains represent negative feed back into the reverberating chains of neurones which constitute pilot behaviour at his allotted tasks.

All of this philosophizing helps us of course very little in our problem except that it underlines the complexity of the organism with which we are dealing and the necessity of treating it as a whole. Thus fatigue is no more a phenomenon of the muscles than of the gastrointestinal tract. It is perhaps more an ailment of the brain than of other individual parts for this like the circulation is an integrating mechanism. But it can hardly be an ailment of the brain alone.

Stresses of Long Missions

Let us consider now the various stresses which result from a long mission. Some of them might be classified as follows: physical, physiological and psychological. The physical stresses are, cold or heat, glare and darkness, noise, supersonics, vibrations, acceleration, slow motions and barometric pressure. At a recent meeting of the CAM the problem of vibrations and ultrasonics was discussed at length and need not be entered into now in any detail. Slow acceleration cause gravitational blackout, slow vibrations in alternating directions cause motion sickness, faster vibrations, long-continued, cause blurring of vision at the natural vibration period of the eye ball or neuromuscular blocks (knee jerk inhibition) and vasomotor disturbances, audible sounds of high intensity cause temporary deafness usually for high tones (the aviator's notch in the audiogram) and supersonics cause heating and perhaps other effects yet to be described precisely. The cumulative effect of all these stresses certainly makes its contribution to the sense of well being or the fatigue and performance of the homecoming pilot after a long flight. Physiological stresses are, hunger or hypoglycemia, anoxia, hypercapnia, intestinal distension, aero-embolism, dental pain, lack of sleep, muscular or neuromuscular fatigue and numerous others. The role of a recent previous infection has been particularly emphasized by Muncie* as a cause of fatigue.

Frequent meals during a long mission are to be recommended. They maintain the blood sugar at a high level and relieve the boredom. A meal, however simple, is something to look forward to and ministers to the fitness of the flyer both physiologically and psychologically. Perhaps there are some foods in general better than others and a high carbohydrate diet has been shown to be advantageous in resisting low O-tensions. Except at extreme altitudes there seems little reason for any special selection of foods except to suit the preferences of the individuals. In the work of Blair in our laboratory even the volume of the abdominal gas could not be shown to be a characteristic of any special foods. Under fatiguing circumstances the powers of compensation can be greatly enhanced by keeping the stomach pleasantly filled and the blood sugar at a high level.

The degree of anoxia encountered in cabin planes is not sufficient to cause any acute symptoms of fatigue and indeed it is not easy to detect changes in performance at 8000 or 10000 feet. When these exposures are continued at this level for 10 hours or more there is reason to believe that the effects may become significant if not serious. Thus D'Angelo** has reported experiments on 6 subjects in a decompression chamber. There was some hyperventilation and those who failed to hyperventilate suffered most from the altitude. The symptoms described were somnolence, irritability, inattention, lack of volition, and fatigue. Some subjects came around to the laboratory the next day to report that the feeling of fatigue still persisted. The experiments were accompanied by some degree of inanition since the subjects were not fed

*W. Muncie. Chronic Fatigue. Psychosomatic Medicine. 3, 277, 1941.
**D'Angelo, Am.Jour.Physiol.

in the chamber after an initial standard breakfast. Control runs at ground level however did not elicit the same symptoms of fatigue. At ground level the subjects were active throughout the ten hours in reading or writing letters but at altitude this was soon abandoned. In long missions therefore, even in cabin planes pressurized at 8000 feet, the cumulative effects of the anoxia may be expected to be one of the contributing physiological stresses. It would be worth a study to determine how little oxygen would be needed, i.e., oxygen for how short a fraction of the flight, to avoid these untoward effects.

Lack of sleep produces a type of fatigue differing from that caused by excessive muscular work and increased metabolic turnover. Sleepiness fatigue can usually be improved somewhat by analeptic drugs such as benzedrine but these have no effect on work fatigue. Even after many hours or several days of wakefulness the performance may be inappreciably affected provided the tests are brief and the motivation is high. Psychological tests do however show a decrement and there is a change in individual behavior and attitude. So long as the motivation is high the performance is not necessarily impaired. Bartley and Chute write, (p.273) "The mere deprivation of rest, etc. although resulting in extreme disorganization (hallucination etc.) does not necessarily induce fatigue". For Bartley it may be stated in explanation, fatigue is a state of mind as distinguished from impairment which represents a diminished performance. Fatigue is a part of the individual's stance with reference to an activity. It involves aversion and a feeling of unwillingness and inadequacy for activity. Thus a well motivated individual may be very sleepy and his performance in tests may be much reduced below normal but he is not necessarily fatigued by this definition. For purposes of the Air Force however, he is fatigued and is likely to make a poor job of landing the plane.

A relatively minor factor in flyer's fatigue is actual muscular activity. The physical effort which goes into the business of flying is small but under special conditions tired muscles might become a contributing factor worthy of consideration. Mere maintenance of an erect and attentive posture for long hours may cause an unusual effort by certain special muscles which might well become a focus of irritation with unfavorable effects upon the performance. One can nevertheless agree with many authors, that fatigue is much more than the overworking of certain muscles.

Most important of all are probably the <u>psychological stresses</u>: anxiety, worry and fear, lack of complete confidence in the navigator or pilot, concern about personal health or the hazards of flight, promotion frustration, preference for alternative assignment, disagreement with the policies of the command, inadequate opportunities for the use of leisure time at the post, disinterest in or ignorance of the overall objectives of the immediate mission, or just plain boredom.

Among the crew members are those high strung individuals of an intellectual type with a keen interest in their surroundings and all the details of the routine duties. Such men create their own internal psychic environment and remain largely impervious to stresses imposed upon them by their inimical physical environment. Their powers of compensation are large; their motivation is high.

There are others whose internal environment is predominantly physiological. Their attitudes are passive, or reflex in nature. Their minds are inclined to be dominated by their bodies; their compensations are physiological rather than mental. Afferent impulses induced by environmental stresses will not be neglected or centrally inhibited but will take their reflex toll of the physiological reserves. The mind will take due note of bodily discomfort and will interpret small aches and pains as harbingers of disabling cramps or essential bodily disfunction. In short the body becomes dictator to the brain. As Prof. Bartlett has pointed out, this condition is likely to lead to difficulties in handling aircraft where reactions are partly guided by bodily sensations of strain and pressure. If these be misinterpreted they give erroneous indications of relative position and orientation. It may be said briefly that the flyer is tired and is performing his duties badly.

Thus we have many different kinds of stresses each of which contribute its quota to the total stress. When the total stress exceeds the powers of compensation, strains begin to appear. The relative importance of different stresses may differ in different men and likewise the type of strain which appears first will not always follow exactly the same pattern and this may also depend upon the particular type of stress and on the individual ability to compensate for the various types of stress. Nevertheless the task before us in an exhaustive study of flyer's fatigue would require the listing of the various stresses in the order of their relative importance for the average man; and to do the same for the resulting strains. Possible remedies for each type of strain should also be searched for.

In the equation which I proposed we can now let x, y, z and n represent various types of stresses and we can write that the total stress $= f_1 x + f_2 y + f_3 z + f_n N$. If x, y, z, and n and the various f's can be evaluated it might be possible to predict fatigue when the total stress exceeded a certain threshold value.

In this connection it might be mentioned that during the war (F.P.R.C. 492) Wing Commander Williams made a study of this point by the interview method asking pilots to rate a number of possible stresses in the order of their importance in their own individual cases. The order finally arrived at was as follows: formation flying, intensive flying (2 nights running), bad weather, strong opposition, long flights, instrument flying, cold, being lost, waiting to take off, difficulty finding target, low flying, briefing too early, cancellation (effect on following night), noise, vibration, need for oxygen. Thus the worst hazards are largely psychological in nature although excessive demands for concentrated attention and skill were also very wearing. And the pilots themselves considered noise, vibration and anoxia the least important of all. A somewhat similar study of fatigue in student pilots was made during the war by Graybiel, Horwitz and Gates by the questionnaire method and provided a similar list headed by anxiety over the hazardous nature of the occupation. (J.Av.Med., 15, 9, 1944.)

Compensations

In the first place I have taken the $\sum$ strains as a measure of the fatigue rather than the $\sum$ stresses. This is merely an expression of the well known power of the organism to compensate for increasing demands by calling upon reserves, pumping the blood at a larger diastolic volume, mobilizing a store of extra red blood corpuscles or extra glucose, vasoconstriction to maintain the blood pressure, bringing new muscle groups into action, or simply making more conscious effort to concentrate on the job. It is only when the reserves are exhausted and the powers of compensation are exceeded that strains appear in the bodily mechanisms and performance is depreciated. With conscious effort the handicaps of blurred vision due to vibration and eye muscle fatigue and the muscle tremor or unsteadiness of the hand due to hypoglycemia can be overcome completely. Thus maximum motivation may greatly increase the compensation and diminish the strain resulting from the stress of a long mission.

Probably the most clean-cut example of a physiological compensation to be found in the literature is Selye's alarm reaction or adaptation syndrome concerning which we shall hear more from our endocrinological speaker, Dr. Hoagland. Briefly, the theory is that any stressful environment or exposure results in liberation of steroid hormones from the adrenal cortex through the intermediation of corticotrophin secreted by the pituitary gland and this sets the physiological stage to enable the organism better to cope with the situation.

As another example we might mention the balance between Cannon's sympathetic-adrenal mechanism and the parasympathetic-vagus-insulin mechanism both of which according to Gellhorn (Autonomic Regulations, New York, 1943) are activated under stress of emotions through the hypothalamus. Usually the balance is in favor of the former and there results a rise in blood sugar. Under conditions of fatigue however, we may imagine that the balance is upset and an excessive secretion of insulin, unbalanced by adrenalin, leads to hypoglycemia and an exacerbation of the symptoms. In accordance with this theory the vagotonic individuals would be more susceptible to this type of fatigue than the sympathicotonics. Some efforts to establish this principle have, I believe, been made and will perhaps be described by other speakers.

The power of compensation in man indeed is very great and very variable and perhaps immeasurable and this constitutes a major difficulty in devising suitable tests for fatigue, or in observing any actual deficiencies due to fatigue. In accordance with the equation we might suggest that it is necessary to use a test which is so stressful that all powers of compensation are exhausted even in the normal rested individual. Then any diminution of his reserves will at once appear as a diminished performance. This is easy in theory but difficult in practice.

President Carmichael* of Tufts recently published his book on fatigue in reading. In his experiments he took continuous records of eye movements, speed of reading and comprehension of the material read, for 6 hour periods and was unable to establish any diminution in actual performance in spite of subjective sensations of tiredness by the subjects. For this test at least the compensations were equal to the applied stresses so that the strains were not measurable. The author suggested that students be trained to disregard fatigue experience during long hours of study. Perhaps flyers should be similarly trained to disregard the symptoms which they experience in long flights.

Another slightly different example is found in a report by Professor Bartlett during the war.** He and his colleague set up an experimental cockpit in the laboratory, a Silloth trainer, and recorded the adjustments made by the subjects in response to a series of artificially applied deviations of course, altitude, horizon, etc. Records were made of side slip, air speed, errors in altitude and in compass course. During a continuous test period of 2 hours he found a steady decrement in the accuracy of the adjustments which the subject made. Yet the subjects were not aware of any such deficiencies in their operations. It seems that their motivation decreased somewhat during this test and Bartlett described his subjects as "not in a state in which the correct behavior

*L. Carmichael, Reading and Visual Fatigue, also Proc.Am.Philos.Soc. 92, 41, 1948.
**F. C. Bartlett, Proc.Roy.Soc., 131, 247, 1943. Fatigue following highly skilled work.

or desired skill cannot be performed but only a state in which it will not be performed unless particular care is taken." "The trouble about fatigue", he writes, "up to very extreme cases, is not that a man cannot put up as good a performance as ever but that he becomes more and more prone to think that he is doing this when in fact he is not." In terms of our equation this experiment means that after 2 hours some of the compensations were exhausted and strains were appearing, while in other functions of the body, i.e., the subjective sensations, they were still adequate.

Bartlett writes as follows on this subject: "Over and over again for nearly every type of job, it has been shown that a man can work right to the verge of exhaustion and still put up an extremely good performance, if he knows how to counter the deterioration which neglected fatigue will inevitably produce. The main reason for this is that every healthy human being normally works a long way below the level of his maximum efficiency. Consequently he can, if need be, meet even long drawn out and serious emergencies by calling upon his reserves and lose little or none of his skill. Naturally the more fit and alert a man is, both physically and mentally, the less he has to fear from anything that fatigue can do, but an ordinary person who is not injured or drugged, or incapacitated in some similar manner, is in little or no danger as a result of fatigue provided he knows something about what to expect and how to guard himself."

Incidentally it may be mentioned that the material of this investigation was used by Professor Bartlett during the war as a Ferrier lecture. Since the investigation was still classified as confidential he was not able to describe his apparatus and it is amusing to see how he talked about his Silloth Trainer in general terms without ever mentioning the word airplane or the occupation of flying. (Proc. Roy. Soc. 131, 247, 1943.)

The most interesting example of compensations however, is found in the Russian Manual of Aviation Medicine by "Honoured Scientist" Professor W. Voyachek. In that estimable book on p. 300 we read as follows:

"In disagreement with the opinion of some foreign authors, we do not find that flyers suffer from any so-called "flying asthenia." The etiology of asthenia in flyers is the same as that of ground personnel. The so-called "flying asthenia" in aviators, which some European and American authors (Fiumel, Bauer, and Armstrong) claim as the effect of prolonged flying, actually is the result of inadequate medical and health-resort facilities, and is associated with insufficient material security under which flyers in capitalistic countries live. The adequate material security under which the Soviet flyers live, the great social aspirations, and the attention paid to the flyers by the country as a whole, are responsible for the absence of asthenia associated exclusively with flying."

In another part of this same book (p. 64) we find that even anoxia can be compensated for successfully under the Soviet regime. We read, "The emotional factor and the socialistic tendency of the Soviet flyer, along with physiologic compensatory mechanisms, play a considerable role in anoxemia. The cheerfulness of the aviator Kokkinaki, who stayed up for 6 hours at an altitude of 5,500 metres without oxygen, is explained on this basis, as well as that of Chkalov, when he and his companions ran out of oxygen during the trans-arctic flight frow Moscow to the Island of Udd."

Whatever truth there may be in these remarks there are certainly some important compensatory mechanisms in the U.S.A. as well as in the U.S.S.R. and they effectively postpone the onset of fatigue or impaired performance.

The Strains of Long Flights

These are both psychological and physiological. Among the former may be mentioned increasing irritability and loss of memory for simple tasks. This was observed to develop after 10 hours in members of the crews of British Catalina Flying Boats engaged in 18 hr. flights during the war. (Sq. Ldr. Winfield FCRC 355). In a later report (F.P.R.C. 685) he related his observations on the fatigue which developed in crews of the bombers which carried supplies to ground forces in the Musk Ox operation in the arctic. This task required 80-130 hours per month of flying under trying circumstances. He concluded that 80 hrs. per month was too much because with this duration the crews were unable to remain in good enough physical condition to meet the trials of an emergency landing if that were called for.

One of the specific strains of long missions is the appearance of brief mental blocks during which the worker suffers a momentary complete lapse of which he may be quite unaware. As work goes on the number of these blocks increase and they last a little longer. In between the blocks however, work is done so much more rapidly that the overall production remains very much the same or may improve."

The subject of mental blocking has been studied particularly by Bills (Physiol. Rev. 17, 436, 1937) and has been reviewed by Bartley and Chute (p. 303). In accordance with the reverberating chain theory this may be called an example of negative feed back. There is some question whether these periods of blocking represent periods of escape from a difficult situation for the purpose of rest or whether they are periods of alternative mental activity - a motivated change of attention. The periods of blocking are correlated with errors of performance and they increase in frequency with fatigue. Bills defines a block as a pause in the task, equivalent in duration to the period of two of the required responses. The responses were color naming, additions or subtractions or the like. This blocking could be eliminated by the introduction of suitable pauses in the work and they could also be diminished by inhalation of oxygen; conversely they could be induced both by fatigue and by anoxia. Bills concluded that the best inhalation mixture for protection against blocking was composed of 50% oxygen, 3% carbon dioxide, and 47% air. The carbon dioxide might possibly owe its effectiveness to a dilation of the cerebral vessels which it produces and blocking may be a measure of the adequacy of cerebral flow. Blocking can be increased by lack of sleep and reaches a maximum after 48 hours of wakefulness when tested by certain tasks.

One does not do mental work with the brain alone but the rest of the body is to some extent also involved. In most of the activities required in long missions in air craft the brain is continually receiving sensory impressions and carrying out appropriate motor activity. Some signs of strain may therefore appear even in muscles and may be detected by action p.d.

Innumerable other strains of a physiological nature may occur. In some respects it may be difficult to distinguish between a strain and a compensation. Both may be physiological or psychological changes in the body, a compensation being a change which improves the performance or state of mind and a strain being a change which results in some impairment or deterioration. Some possible physiological strains which might be suggested are, vasomotor instability, accumulation of blood in the dependent parts, neuromuscular incoordination, intestinal immobility, indigestion, diminished renal clearance, increased glomerular permeability, electrolyte imbalances, excess of plasma K or Mg, (not found in truck driver) diminished sensory acuity (as loss of auditory acuity, blurred vision) possibly increased awareness of unpleasant sensations, endocrine hypo or hyperactivity (as increased secretion of corticotrophin for stimulating secretion of steroid hormones from the adrenal cortex) metabolic disturbances or hepatic dysfunction. Any of these may serve as fatigue tests on occasion.

Fatigue Tests

A quantitative analysis of the relative importance and probability of the several strains might also be considered but in order to accomplish any quantitative evaluation of stresses or strains it is necessary to have some fatigue test by which the importance of each individual stress can be measured. Such a test should be (1) independent of cooperativeness of the subject or his motivation. (2) Easy to measure without interfering too much with normal duties.

It is too much to expect that there is or could be any single test which would fill this need but several tests might be found and one good test, even though incomplete is better than several poor ones. The record of the number of errors made in a model cockpit, as used by Bartlett, sounds ideal at first, but it might be a measure of the increasing carelessness rather than fatigue. The motivation is clearly an important factor. A continuous record taken during a long flight of the number of eye-winks, or the number of slow delta waves in an electroencephalogram, as in the Randolph Field Anoxia meter are examples of tests which require no cooperation from the subject. The record of the summated action potentials of the eye muscles as used by Dr. Kennedy at Tufts is a test of this nature which promises to be very useful. Biochemical changes in blood and urine would offer an ideal type of test.

Honeyman (FPRC 515) measured the after contraction (AC) in his subjects. This is the involuntary shortening which occurs after 15 sec. of intense voluntary contraction. He found that fatigability as shown by a low score on instrument flying was particularly marked in subjects who have only a short average duration of the A.C. and who do not show an increase in AC after the period of instrument flying.

In the field of biochemistry we have the excretion of the 17-ketosteroids. If this can be established as a thoroughly reliable stress hormone it would greatly facilitate the investigation of flyer's fatigue. The actual muscular activity is so low that there is hardly any use looking for increases in lactic and pyruvic acids in the blood or any of the metabolic changes normally accompanying ordinary muscular fatigue. One other possibility is the determination of the ratio of polypeptide to albumen in the urine as suggested by Gukelberger and Abplanalp (Deutsch. Arch f. Klin. Med. 187, 392, 1941) in place of the Donnaggio reaction. Both are supposed to be a good measure of the permeability of the glomerular capillaries and may be taken as a measure of fatigue. This claim may deserve investigation but it is certainly far from proven.

Obviously, if some sort of a fatigue hormone or toxin could be found it would be a great boon to any fatigue investigation. From this point of view it might be worthwhile to search in the urine or plasma for unknown substances in conditions of extreme fatigue by the use of such methods as infra red spectrometry, electrophoretic patterns or polarographic analysis.

In recent years the biochemists have been very successful in explaining everything by enzymes. An enzyme-inhibitor as a cause of fatigue is badly needed and it is certainly not difficult to dream up some oxidative system, the inhibition of which would explain the phenomena to perfection. If this would also serve as a test of fatigue a real advance would have been made. All these fatigue syndromes are, to some extent, alike. They have something fundamental in common. What is it? May I express the conviction that there is something tangible and that it can be found.

General Discussion

The field of fatigue is not yet in the condition of physics when the atomic bomb was put together. The necessary background of science is not yet available. You cannot derive the answer merely by spending millions of dollars in the investigation. The best we can do is to follow up all promising leads and encourage with adequate finances all those who offer hopeful ideas. It cannot be predicted where the "break" will come in the wall of ignorance which bars our way. Our present difficulties have been adequately defined by a series of symposia on the subject and a number of published investigations. As Dr. W. H. Forbes has remarked in a former symposium published in (Psychosom. Med. 5, 154, 1943), "The study of fatigue is now at the same stage of development, that the study of disease was, in some hypothetical pre-Hippocratic period when everyone spoke simply of "sickness" and only a few advanced thinkers spoke of "hot sickness", "red sickness", "thin sickness", "belly sickness", etc."

The analogy to disease in general is a very apt one. In fatigue as in disease there may be certain factors which are common to many if not to all types of fatigue. Fever is the most common symptom of disease and represents a disease test which however, is not infallible for all types of disease. Similarly we may find a fatigue test possibly of a biochemical nature which will measure many types of fatigue but not all of them. The best approach then is to study each fatigue entity by itself in as much detail as possible, learning the stress which caused it, the compensations which alleviated it, and the strains which resulted and taking the measure of the strains as a measure of the resulting fatigue. Eventually a body of knowledge concerning fatigue will result but only pari passu with the advance of clinical, physiological and psychological knowledge.

For the study of fatigue is the study of the whole field of medical science. Almost any discovery in physiology, psychology, medicine or psychiatry is a potential contribution to the study of fatigue. Let us not therefore be too grandiose in our ideas about a program for the study of fatigue. Let us not flatter ourselves that we are in a position to formulate a program which will accomplish much if any more than the other programs of a similar nature which have been set up in the recent past, such as the study of Fatigue in Truck Drivers conducted recently by the Public Health Service. The chief value of such a program is that it requires a certain number of persons to take time out to make sure that all the latest scientific developments have been adequately applied to the practical situation and this is indeed important. Although the general outcome of such a study can perhaps be predicted fairly well it is certainly worth making on a limited scale and on the level of actual military operations - not in the laboratory alone. But let us not make it with the idea that this will be the study to end all fatigue studies. The best policy now is watchful waiting, the prepared mind, active thinking, study and research on all promising ideas. Meanwhile there is much that can be done in a practical and common sense manner by contributing as much as possible to the avoidance of all the well known stresses which together contribute to the onset of fatigue and in tabulating for each case in as much detail as possible the physiological changes which accompanied the symptoms.

Operational Aspects of Fatigue - Colonel William J. Kennard

Dr. Fenn has well covered the problems more capably than I could have. The Air Forces are concerned with fatigue in flying personnel as well as its application to ground personnel in the use of radar, flight control, etc. It is another problem of anxiety to the air crew. The problem has been attacked concerning for what time a radar scanner can work continuously. These are practical problems for flying personnel. People get tired physically and mentally.

In the past, acute fatigue has been handled in the convalescent hospitals. That is, we have turned it over to the psychiatrists only when it became severe. I wonder if we shouldn't bring the psychiatrist into the picture earlier? The crew of a plane, under adverse conditions, may have great motivation which does not necessarily improve its efficiency. On a trip to Japan we had a pilot experienced in planning and flying long-range trips. We got only two to three hours rest at Roswell, New Mexico and that was the last real rest we had. We took time for refueling, bathing, and shaving, but the crew worked most of the time. On the way to Guam, the question arose as to whether to go directly to Tokyo, but we decided to go to Guam. Here we laid over long enough to shower and took off again. We came into Tokyo in the midst of a typical tropical storm. Outside of Tokyo there was evidence of fatigue in everyone and as we got in closer we passed over and missed the one check point which we should have caught as our personnel was experienced in flying in this area. The radar scanner said that he saw Tokyo Bay and we turned around and went back to a check point and came back in for an instrument landing with a 200 foot ceiling after 60 hrs. on the trip with all but 2 or 3 hrs. actually in the air. Fatigue was not so great that anyone collapsed but they explained it as being "so tired". As we were planning on a 26 to 40 hr. mission we took two crews but that was even worse because of the crowding that occurred. Planning in jet planes is to reduce the size of the crew from 3 to 5 men rather than 9 to 11 on long-range bombers. We have the same problem in fighter aircraft that has 8 to 13 hours of fuel and range. It is thought that we might use only one or two pilots. So, it is most important to know how long can the body efficiently function. When does fatigue become a hazard? The

British limit transport pilots to 1000 hours of flying per year, 300 of which may be in any three months or 120 hours in one month. They figure this time as the amount of time out of bed rather than actually in the air. This is done because much of the waiting time for bad weather etc. is as strenuous from the standpoint of fatigue as actual flying.

What is the maximum number of flights that one crew can take in a certain time? What is the maximum duration of these flights, continuous and broken? We wish to know how accumulative fatigue fits into this picture and what the early signs of such fatigue are.

Drugs have been worked on but have not been accepted by the aircrews as good practice and there is much resistance to their use. The type of clothing is important to fatigue. That is, should the aircrews wear or take with them clothing for all anticipated emergencies such as, arctic landings, etc. The use of oxygen does contribute to fatigue. Food requirements, time of intake, etc., quality of food in the flight ration all pertain to fatigue. We should determine the duration of the time of duty for each crew man.

We should also consider the use of drugs. They should have a rapid effect, and a specific duration. The crew could use the drug near the end of the flight. The present drugs have uncertain effects.

General Armstrong: Pilots put anoxia way down the list as a cause of fatigue. I would suggest that they do not associate post-flying fatigue with oxygen lack. A second factor is fatigue at high altitude without anoxia. It is not definitely established but we have experimental evidence that this occurs. This gets into the realm of the subjective that you just "feel more tired" at 18,000 feet or 35,000 feet with adequate oxygen than at low altitudes. I believe that there is some factor important here, perhaps subclinical aeroembolism could be the cause of it.

In England the Eighth Air Force operated on seven out of eight days. This was the longest period of sustained operations. There were long missions and we requested an analysis of landing accidents. The rate did not go up. The crew got two to three hours of sleep per day. If this means anything, the men do compensate at landing but may get careless at altitude. We have no idea of how many were lost on the missions due to fatigue. Also, the crew man who has nothing to do seems to get the most fatigued; that is, he feels more tired than the rest of the crew.

Psychiatric Aspects of Fatigue
Dr. Harley C. Shands and Dr. Jacob E. Finesinger

In this discussion, the conclusions which we have reached have been a product of exploratory psychiatric interviews in a large group of patients with unexplained "chronic fatigue."

We have used the term fatigue only in the limited sense of a feeling of weariness. We have found it useful to employ the term impairment to cover (1) decrement in output following exertion and (2) physiological and chemical changes occurring in the body as the result of exertion, two definitions frequently included as meanings of fatigue. There is a relationship between fatigue and impairment, but it is scarcely ever a direct or constant relationship.

The combination of symptoms exhibited by these patients has been about as constant as that in the usual clinical description of a syndrome. They complain of tiredness, disagreeable sensations distributed widely throughout their bodies, insomnia, restlessness, difficulty in concentrating, tenseness and anxiety and a feeling of depression.

When asked to define as accurately as possible what is involved in the feeling of fatigue in so far as it is distinguishable from the other feelings that they have, the patients describe difficulty in initiating and completing essential daily activities, frequently with special difficulty in certain lines. They say, "I can't get started, I don't want to do anything." The description of the feeling is expressed in essentially motivational terms.

There are an almost infinite number of associated bodily sensations. These seem to have no constant pattern and may be expressed as discomfort, pain, tenseness, aching, and feelings of weakness which may involve any part of the body.

Many of the patients complain of feeling restless all of the time. It is interesting that some who complain of the severest fatigue also complain of inability to be still. They may have a strong desire to rest, but upon lying down the drowsy feeling is replaced by tenseness, and they are forced to get up and occupy themselves in some sort of activity, but they are unable to sustain interest in any one thing. A related condition is an inability to concentrate or to think clearly, with a cloudy or dazed feeling in the head or even headaches.

There is tenseness of varying degree, at times described as a feeling of tightness and at other times merging into frank anxiety, either of a diffuse type or else precipitated in anxiety attacks. Frequently, the patients are very irritable.

The feeling of depression varies, and at times is not advanced as a complaint but may be inferred from the fact that the patients describe "causeless" crying and appear "blue" or moody. In these patients, further diagnostic and therapeutic exploration usually reveals in a short time the presence of the depressive affect which it has in some way been possible for the patient to suppress.

The normal variation in state of well-being during the course of a day is frequently radically altered in these patients, although not consistently in all patients nor constantly even in any one patient. There may be a reversal of the usual trend, with fatigue in the morning and a feeling of well-being at night. The frequent complaint of insomnia seems to be related to this alteration in daily habits.

A further striking characteristic of the syndrome as we have seen it is the selectivity of the fatigue; there is a marked difference in the severity of the symptoms in different situations. In a number of instances marked temporary improvement has occurred in connection with a change in location, a vacation trip, or the pursuit of a more pleasing occupation.

At the beginning of our study of these patients, we had an impression that we would probably encounter individuals who complained of chronic fatigue as an isolated symptom. One of the most interesting facts true of the whole series is the contradiction of this impression. In each case it has been possible to make a diagnosis of some type of psychiatric disorder, usually that of a psychoneurosis with features of anxiety and depression.

In all of these patients the onset of fatigue could be traced to a definite period of time; at the same period, other symptoms had developed, usually in a life situation which imposed stress on the adaptive capacity of the individual. In addition to the "macroscopic" picture of the onset or severe chronic exacerbation of symptoms, in all of the patients whom we have studied intensively, there have been instances in which fatigue appeared suddenly within a few minutes, enabling us to observe what might be called the "microscopic" aspects of this condition.

The onset and major exacerbations of the symptoms correlated, in the cases studied in detail, with a major change in an important human relationship. Such changes included marriage, the loss of a key figure in the patient's environment, childbirth, military status, and alterations in job status. In the latter connection, it was interesting that, although most patients seemed to react most severely to losses in status, there was a small group who developed symptoms at the time of a promotion.

In the detailed investigation of a single instance in which patients described the sudden appearance of fatigue when it had not been noticeably present before on the same day, it was found that in each instance there was also the appearance of a sudden intense emotion. It was possible to trace the affective components with some assurance in many cases, and in these, the emotions present were various mixtures of anxiety, guilt, depression, and the feeling of having been rejected.

We believe that in our patients fatigue is a psychoneurotic symptom. With this conclusion, however, we are then faced with the task of making sense out of fatigue viewed in this light, and also with the necessity for finding a distinction between the occurrence of fatigue as a simple result of activity and as a psychoneurotic symptom.

The stimuli associated with the onset of fatigue are those which demand immediate action of an aggressive type. Because of the setting, the other individuals involved, and the patient's personality, the demanded activity cannot be carried out, and conflict occurs. If the situation is an important one, the individual is unable to ignore the challenge (even though the challenge may no longer be conscious) but returns again and again to it or to other happenings in his life which by association pose similar problems.

There are conscious and unconscious elements in the production of the symptoms. The initial problem was conscious or close to consciousness, but because of the inability to resolve the problem by appropriate motor activity, an attempt was made to get rid of it by excluding it from consciousness. The emotional needs could have been satisfied by the appropriate activity; but the necessary activity was of such an aggressive nature as to be blocked by the patient's conscience or by his fear of the consequences. These needs persist unconsciously and exert a persistent force.

Consciously the patient is tense and may have an awareness of feeling that at any moment he may explode into violent action, a possible consequence associated with anxiety. The complaint of restlessness reflects both the necessity of constant occupation to avoid allowing the forbidden topic to come into consciousness and also the attempt to find a solution by displacement of the conflict to situations other than the dangerous ones.

Frustration of the original need by the blocking of the appropriate activity leads to heightened aggression; the complaint of irritability that these patients make seems a generalized hostility towards an environment which has become menacing as a result of the patient's projection of his own feelings onto his surroundings and associates. A further consequence of the feeling of being menaced by a hostile environment is that every stimulus from outside is appreciated as potentially dangerous and cannot be ignored but must be tested by the patient. Not only is the patient more irritable in the lay use of the term, but also his nervous system is more irritable in the physiological sense. The scattering of attention involved in this process makes concentration impossible.

The fatigue itself seems most closely correlated with the actual blocking and with the patient's awareness of his inability to solve the problem. The depressive elements are apparently a function of the patient's loss of self-esteem in his realization of his inadequacy.

The large number of ways in which these patients complain of discomfort in various parts of their bodies is part of their heightened awareness of themselves, coincident with a withdrawal of interest from the outside world. Bartlett speaks of the same process in his normal pilots in states of severe fatigue, as the "growing dominance of the proprioceptive aspects of the situation."

In the majority of the patients, the activity that is blocked affects only certain portions of the personality, and when these dangerous areas can be avoided, it is possible for the patients to function quite successfully.

In a manner similar to the way in which anxiety is the conscious portion of the primitive response preparing an individual for sudden and violent activity either of fight or flight, fatigue is associated with the other type of primitive response to severe danger, that of immobilization by fear. There is a good deal of evidence in our patients that they are "playing possum" or "playing dead" to handle the inescapable danger.

In successful psychotherapy with these patients, the therapist functions in a variety of ways. In the early stages of therapy, an important function is to support the patient by giving him the feeling that he is no longer alone but has now an ally who is fighting along with him. There is frequently at this point a marked decrease in the severity of the symptom. In the further development of the transference relationship, fatigue reappears when the patient is forced to cope with emerging aggressive impulses directed at the therapist. At this point the therapist helps by enabling the patient to gain insight into the original problem as it emerges in the current situation, and to work the problem through successfully in the new context.

Many of the recent research developments in the study of skills and skilled behavior provide provocative ideas in this context. If one may think of the life of an individual as an exercise in the applied skills of making and maintaining satisfactory relationships, his happiness is dependent upon the degree of success which he achieves.

In the regulation of skilled activity, there are two thresholds of major importance. There is, on the one hand, the threshold of what is worth doing ("threshold of indifference") and, on the other hand, that of what one is able to do ("threshold of discrimination" or ability). As Bartlett points out, in the beginning of his experiments, the two are roughly equal, but as time passes, they diverge sharply, with more and more elevation in the threshold of indifference. We suspect that in normal individuals the threshold of ability is the more important limiting factor, whereas in neurotic persons the threshold of indifference is predominant.

In the study of fatigue or of skill in the human being, it is important to bear in mind that criteria of achievement alone are inadequate. There is evidence that the feeling of fatigue is correlated not so much with the individual's achievement as with his own awareness of the smoothness and efficiency of his actions. In many instances, the first sign which warns one of an impending major breakdown in integrative functioning is tiredness; this may take place long before any objective impairment can be noticed.

To recapitulate: the stress imposed in psychoneurotic fatigue is an alteration in an important human relationship, and the most stressful part of the process seems to be the development of aggressive feelings which can neither be expressed nor sublimated. The strain resulting is a conflict, with the aggressive action blocked by feelings of guilt,inferiority, and fear. The blocking action spreads to involve many activities not popularly regarded as aggressive, and it results in an extensive limitation in the field of social action. The amount of strain is a function of the patient's ability to readjust his relationships so as to restore what might be called his social homeostasis.

Activity in these patients is blocked by affective states, the emotional charge of which derives from other similar situations which may be quite distant in time, while activity in normal individuals is limited by decreasing ability to perform, a decrease closely correlated with the immediately preceding exertion. The common psychological state is an awareness that the problem has gotten out of hand.

The problems posed here are among the most important ones facing the world today. Fatigue and psychoneurotic disorders (at times it seems that the two are almost synonymous) are perhaps responsible for more individual and social morbidity than any other class of ailment.

The most accurate test that is now available to estimate the amount of difficulty is the clinical opinion of a good psychiatrist. Much investigation is needed to establish the factors entering into his judgment. For our patients, the important therapeutic tool is psychotherapy. The first problem of psychotherapy is that of communication between patient and therapist. This communication has at least two parts: there is the necessary verbal interchange, but further and more important is the indefinable phenomenon known as rapport, an exchange of feelings mediated by words in large part but quite distinct from them.

Studies of techniques aimed at mediating more effective communication between individuals presumably would have wide applicability in all sorts of problems of individual and social functioning.

Reference: Bartlett, F. C. The Measurement of Human Skill, Brit.M.J. 1: 835 and 877 (June) 1947.

Dr. Richard Masland: Effort should be made to interrupt the stimuli from the outside to central nervous system.

Psychological and Visual Aspects of Fatigue - Dr. John L. Kennedy

This paper summarizes experimental work on output impairment in normal human subjects conducted over a period of 10 years at Tufts College. These studies illustrate the essential psychological findings of many investigators concerning "fatigue". They were conducted with objective indicators of performance such as continuous 6-hr. records of all eye-movements in reading and intermittent objective tests of visuo-motor tracking. The conditions for inducing output impairment were 10 mile hikes, 50 hr. sleep deprivations and various degrees of severe physical exertion. Conclusions from these studies may be stated as follows:

1. Output level remains constant when testing is intermittent and the work consists of short-term heterogeneous tasks. College students can and do compensate during the testing period to maintain a relatively constant output up to 4 hrs. of continuous work.

2. Extreme extraneous fatiguing conditions such as the 50 hr. sleep deprivation plus homogeneous (monotonous) work will occasionally produce output impairment, to a degree, both statistically and practically significant. Subjective report of fatigue usually occurs long before objective impairment.

3. Bonus payments for good performances always restore output to its original level.

4. With college student subjects, 6 hrs. of continuous reading showed no decrements in reading performance when the reader was given comprehension tests at the end of each 25 pages. In a previous study, statistically significant decrements in reading performance were obtained with 4 hours of continuous reading when no comprehension tests were used.

5. All of these results point to the importance of level of motivation as the important determiner of output impairment in the intact normal person. Motivation is a catch-all term, which, in normal adult human subjects, stands for a large number of relatively unknown sources of variability.

Further work on fatigue in our laboratory has been concentrated on more delicate kinds of response indicators and on physiological measures of variability of muscle activity. In 1946, the Special Devices Center, Office of Naval Research, asked us to look into reports from Germany that an Alertness device, working on frequency changes in the alpha rhythm, had been developed for use by the German Air Force. It was rumored that Dr. Kornmüller was the inventor of the device. We began studies of reaction-time to aperiodic stimuli and concurrent recording of alpha rhythm in subjects during several hours of continuous observation. The variability of the electroencephalogram results lead us to shift to muscle spike recording. After considerable preliminary experimentation, we were successful in demonstrating a useful relationship between muscle spike frequency from electrodes placed on the forehead over the eyes and reaction-time. (See Kennedy, J. L. and Travis, R. C. "Prediction of Speed of Performance by Muscle Action Potentials", Science, 1947, 105, 410-411.)

The next step was to shift from pure frequency measurement, which yielded rather variable results, to an electronic accumulator or integrator, which would smooth the subject's muscle spike output. (See Travis, R. C. and Kennedy, J. L. "Prediction and Automatic Control of Alertness. I. Control of Lookout Alertness", J. Comp. & Physiol., Psychol., 1947, 40, 457-461.) This paper reports a uniform relation between integrated muscle spike output from the same placement and reaction-time in a simulated look-out situation.

Tests have been conducted in a simulated aircraft pilot or driving situation, in which the subject steered a target continuously for 2-3 hours, during which he was required also to react to an occasional red warning light placed 25° peripherally from the central visual task. (See Kennedy, J. L. and Travis, R. C. "Prediction and Control of Alertness. II. Continuous Tracking." J. Comp. & Physiol., Psychol., 1948, 41, 203-210.)

These latter tests confirmed the results of the first paper in demonstrating that fluctuations in amplitude and frequency of the physiological variable of muscle potential are correlated with lapses in attention or readiness to respond on the psychological side.

In association with the Electrodyne Company of Boston, a portable amplifying and detecting apparatus, small enough and light enough to fit in planes and automobiles has been constructed. Tests in the presence of electrical noise are satisfactory enough to suggest that a practical electronic device can be constructed to automatically alert personnel in a monotonous, tiring situation. Development of electrodes has made possible a light-weight head band with small sponge-rubber electrodes which may be worn for hours without discomfort or loss in electrical conductivity.

<u>Dr. J. W. MacMillan</u>: Spot tests are no good. The pilot can compensate to good performance. In the past year only have long-term tests been designed as mentioned. These are useful in the analysis of - what is fatigue itself. What is the reliability of tests for individuals?

<u>Dr. Kennedy</u>: We were working with the drop-out point; extreme sleepiness, as in a sentry. We are not too sure of the concept of a critical point between reaction time of one second and two-thirds of a second for example. We may have to adjust the critical point for each individual.

<u>Dr. J. J. Smith</u>: There are two factors in fatigue: 1. Basic psychic make-up, 2. External factors and the compensating action of the individual. No. 1 is

most important of all. What can we do about it? Can we go any further in this direction? Is it possible to apply it to military medicine? This gap is unfilled. There appears to be some physiological gap between the psychiatric opinion and actual physical tests. We should study a small number of individuals in relation to basic psychic make-up. This might lead to elucidation of the effect of flying fatigue on the make-up of the individual.

General Armstrong: Can you evaluate a man as to his susceptibility to fatigue?

Dr. Kennedy: We are interested in the body type of subjects. Excess weight seems to lead to boredom more so than a long lean person.

Dr. Shands: We can draw some sort of tension score. Below a certain level people are indifferent. Except excessive tension is also disabling; the individual gets too tense. This is the case with the obsessive type of personality, the person is always doing something to avoid the problem.

Dr. Kennedy: There are several early signs of accumulative fatigue. One sign of the early output is the onset of oscillations in physiological function which may be the person beginning to nod, etc.

Pharmacological Aspects of Fatigue - Dr. Carl F. Schmidt

Two basic questions are involved here, as in any pharmacodynamic analysis:- (I) Since drugs do not introduce any new functions but merely increase or decrease the activity of systems already present, what is the physiological and/or biochemical basis of fatigue? (II) Since no potent drug can be counted upon to exert only one action, how many drugs influence the pattern of fatigue to the advantage or disadvantage of the organism? Existing information does not offer a definitive answer to either of these questions, but there are some interesting possibilities.

(I) The physiological or biochemical basis of fatigue is bound up with the fact that the central nervous system usually is the limiting factor in the ability to withstand fatigue as well as anoxia. Since the early work of Haldane and Barcroft it has been generally realized that acute anoxia simulates drunkenness while chronic anoxia simulates fatigue. It is unlikely that the two types are completely separate, more probable that they coexist as different manifestations of the same fundamental processes. For purposes of simplification we may assume that the fundamental cause of fatigue in the central nervous system is the same as that of the symptoms of anoxia. Two questions then arise:- (1) How can anoxia of the neuraxis be produced? and (2) Why does anoxia lead to fatigue?

(1) Anoxia of the brain, as of any tissue, can be brought about by (a) diminution in the supply of oxygen (in the inhaled air, in the volume carried by the blood, in the volume of blood flow, or in the ability of the cells to take oxygen out of the blood); (b) increased demand for oxygen to the point at which the available supply cannot meet it; and (c) both (a) and (b) together, which is what characteristically occurs in aviation. Factor (b) has not received much attention until recently, though from the standpoint of drug actions (desired and undesired) it is of utmost importance.

(2) Why should continued anoxia of the brain lead to fatigue? The answer is undoubtedly related to the fact that the oxygen requirement of the brain is higher per unit of tissue than any other organ except the kidneys and heart at rest, and is practically doubled during the increased activity associated with a generalized convulsion. Following this, however, there is a prolonged period of depression of both cerebral activity and cerebral oxygen uptake with gradual recovery. It is reasonable to suppose that the depression is due to anoxic damage to brain cells by increasing the call for oxygen to a level which cannot be met even by the increased supply. This depressed state following a convulsion may be regarded as an exaggeration of the pattern of fatigue.

A schematic and undoubtedly greatly over-simplified conception of the direct relationship between functional activity and oxygen utilization in the mammalian brain can be found in the so-called Acetylcholine Cycle (see Ann. Rev. Physiol. 7: 243, 1945). If one assumes that unstable chemical substances, charged with chemically bound energy derived from aerobic oxidation of a carbohydrate, serve as "chemical amplifiers" to increase the intensity of the disturbance created by a nerve impulse impinging on a neuronal system, one can see not only why the amount of "amplifier" should vary directly with the rate of oxygen utilization, but also why excessive activity may lead to depletion of the available supply of such material and thus to fatigue.

(II) Drugs can enter this picture in several ways. (1) Stimulant drugs may increase the existing rate of oxygen utilization and thus bring about an increase in excitability that would override the ordinary signs of fatigue. This is a familiar effect of benzedrine, pervitin and others of the group. Experience during World War II indicated that the effects of fatigue were not removed in this way but came back again when the stimulant effect wore away and required a relatively longer period of rest for complete recovery. Controlled studies of the effects of various drugs on anoxia tolerance in man were numerous, but the results must be evaluated with the knowledge that almost everything that was tried appeared to have a beneficial effect (methylene blue, nicotinic acid, ammonium chloride, high carbohydrate diet, benzedrine, pervitin, adrenal cortex, etc.). Apparently the methods used in such studies were not adequate to reveal the true facts concerning the actions of drugs on the ability of man to withstand anoxia, and the same is likely to be true of the effects of fatigue. At present it appears most probable that a deficit of rest made possible by a stimulant drug will have to be paid off within a relatively short period, and there is no evidence that any agent is capable of restoring a fatigued central nervous system to normal appreciably more rapidly than rest alone. This situation may change as the result of studies of the cerebral utilization of various metabolites (J. Clin. Investig. 27: 500, July 1948), but the purely empiric approach used in the past holds little promise of better success in the future than in the past.

(2) Depressant drugs theoretically could improve matters by decreasing the oxygen requirement of the brain, thus (if the basis of fatigue is oxygen-lack) restoring a favorable balance between oxygen supply and oxygen demand. Actually any such advantage would necessitate marked interference with cerebral functions, which would preclude continued activity and force a period of rest.

(3) A special place is reserved for drugs which produce euphoria and thus deceive the central nervous system into tolerating a previously unpleasant or unbearable situation. The best-known members of this group (morphine

and its congeners, alcohol, demerol, amidone) are used primarily as analgesics and the euphoria is generally regarded as undesirable because it is likely to lead to addiction. The reason for the coincidence of analgesia and euphoria is at present unknown, but every drug that produces euphoria apparently can also produce addiction. According to existing information, substitution of drug euphoria for fatigue is not a justifiable therapeutic procedure. The better plan is to face the fact that fatigue is a sign either of an abnormal situation (perhaps anoxia) in an otherwise normal central nervous system or a central nervous system that is incapable of withstanding otherwise mild signals of distress.

The ability to tolerate fatigue is intimately concerned with such matters as personality and consciousness, for which a satisfactory biochemical basis certainly does not exist now. According to Kety (J. Clin. Investig. 27: 489, July 1948) - - "the higher psychic functions are associated with biochemical changes so subtle and complex as to render any attempt to describe them in terms of mere oxygen utilization no more adequate than to predict the fidelity of a radio by its power requirements". Yet this is the only truly objective estimate that is now available.

Dr. Hoff: In regard to the use of benzedrine and the use of drugs in anoxia, performance is relatively good where there is a stress and motivation. Wandering of attention in routine procedures is a greater problem. It might be possible to use drugs at that time. Patients using benzedrine say that their attention is maintained even though they feel the effects of fatigue. Dilantin increased the resistance of small animals to anoxia. The mechanism is not known. It appears that the action is specific and prevents over-reaction of nerve cells. We should explore how this works in the prevention of fatigue.

Dr. Bronk: Colonel Kennard feels that an early sign of fatigue is a change in weight.

Colonel Kennard: I feel that a change in weight is indicative of a man's general well-being. If a man had lost a certain per cent of weight below normal, this was due to fatigue. We found it was very true. Of course, if a man lost 25 lbs. he should be taken off duty. But a loss of only 3 or 4 lbs. also indicated a man should be off flying until he regained his weight and this would prevent over-fatigue.

The Digestive and Nutritional Aspects of Fatigue in Airmen - Dr. E. S. Nasset

Some stresses of flight which may affect digestion and nutrition are: (1) Uncertainties of flying, (2) Anoxia, (3) Motion, (4) Noise, (5) Extremes of temperature.

The strain which develops in response to the uncertainties of flight (weather, lack of confidence in crew and equipment, extent and intensity of enemy opposition) may be characterized as apprehension. The overactive sympathetic-adrenal system leads to inhibition of both the muscular movement and the secretory activity of the ailmentary tract.

The stress of anoxia ultimately leads to a strain also manifested by inhibition of gastro-intestinal functions. Gastric evacuation may be delayed even at 8000 feet which indicates that 10,000 feet may not be a safe altitude without some oxygen or a pressurized cabin. On long flights especially there may be cumulative effects which heretofore have gone unrecognized on account of the relatively short exposures to altitude used in much of the early work.

Extremes of temperature, noise and motion all tend eventually to induce a general inhibition of digestive processes.

The fundamental problem in the nutrition of the airman is the same as for any other man, namely, he must ingest a diet which on the average will supply his requirements for essential nutrients. The tendency to specialize the airman's diet to gain some specific temporary advantage may, in the long run, work to his detriment. It seems clear that a high carbohydrate diet just preceding and during a flight will increase altitude tolerance but if an airman is airborne several days in each week and subsists during this time on a carbohydrate diet, he can soon incur a serious deficit of certain other nutrients. To compensate for this deficit he may be forced to eat, while on the ground, a diet which is unbalanced in the other direction and hence not wholly acceptable. The aim should be to obviate the stress of anoxia by proper engineering of aircraft and equipment and to allow the airman to eat a normal well balanced diet. It is important also to indoctrinate the airman with the importance of an adequate diet. Experience in the 9th Air Force during the last war proved that it is entirely feasible to teach the fundamentals of nutrition to airmen and to realize desirable results therefrom in the way of improved eating habits.

A successful attack on the problems mentioned above depends greatly on a definition of the stresses in quantitative as well as qualitative terms. For example, exposure to any given altitude does not have much significance unless the time of exposure is known. A time-intensity expression for all stresses seems, therefore, to be a logical starting point in a study of the strains which develop in flight and especially in regard to long range flying.

Remedial measures should start with engineering the aircraft and its equipment to reduce stresses to the point where the airman can make successful compensations. Human comfort should be a prime consideration in the design of an airplane. Even with the best that the aeronautical engineer can do, it will still be necessary to select carefully all prospective airmen for emotional stability and physical stamina and to provide a thorough and well rounded training in all aspects of life as an airman.

<u>Dr. Ivy</u>: I feel that we should distinguish between "at base" weariness and fatigue from flight. The conditions "at base" may affect the conditions in flight. A man can lose 1 to 3 lbs. during a long flight. This need not cause a progressive loss of 25 to 30 lbs. There may be some disturbances "at base". We should study the appetite and consider factors affecting it. Frustration, anxiety, worry, and nerve strain will cause loss of weight in most but some persons react by eating more and become obese. This affects the colon in the same way. We found an increased urge to stool in 88 - 90 per cent. 10 to 15 per cent were just the opposite.

"Medical students disease" (fatigue) may have a low grade infection. They may have a low oxygen consumption and basal metabolic rate of a -15 to a -20.

They cannot relax. If the basal metabolic rate is increased with thyroid extract the easy fatigability disappears. This process is prone to occur in athletes and students who work in the summer and then study and do not exercise for six to eight months. They develop chronic fatigue, dizziness on arising. They should get some exercise one to two times a week for a few weeks. These things should be considered at the air base.

There are some questions which the Air Force could look into for in-flight fatigue. These things have been of value in industry. Good physical condition prior to flight; testing in a link trainer or altitude chamber; activity vs. inactivity in flight and should it be mental or physical inactivity; what should be sleep methods in off time. Long flights with low B.M.R. and with high B.M.R. should be tested. What should be the nature of in-flight feeding? I am not sure about any regular in-flight feeding. Perhaps we should have small, frequent meals. In general, one should not eat in the presence of anxiety. The aircrews felt better on hard candy. This also helps them to keep awake and it gives nourishment and appeases the appetite but does not overload the digestive system.

I think we should not be satisfied with the results of tests for fatigue. We should place more stock in the feeling of well-being of the individual. Some people can pull themselves together so that no test can find a deficiency. Marines who were kept awake three nights had hallucinations and sore feet from marching but showed good marksmanship in target practice. One thing this proves is that I don't want a marine to shoot at me even when he is asleep. We should use objective and subjective tests.

Dr. Dill: We had experience at Wright Field and with the Quartermaster Corps evaluating rations for the infantry and the Air Force. We had trouble with rations in general in North Africa. The missions were for 6 to 8 or 10 hours. The aircrews ate anything they could get in flight. They were tired of K rations and wouldn't eat them. Many ate sandwiches. They commonly lost weight and none put on weight. The universal experience in the infantry when the men were returned from battle was that they gained weight very rapidly and that their spirits went up at the same time. We should have occasional checks on body weight. Men wouldn't eat pemican. A man becomes even more particular under stress. You cannot educate a man to eat what is good for him.

Dr. Guest: In long flights the whole idea regarding high carbohydrate diet as concerned with aeroembolism should be re-evaluated.

Some Responses of the Human Adrenal Cortex to Stress - Dr. Hudson Hoagland

The adrenal cortex, unlike the epinephrine secreting adrenal medulla, is not under direct nervous control. The adrenal cortex is activated by one or more protein hormones (corticotrophins) released from the anterior pituitary. The cortical hormones all belong to the chemical family of steroids - four-ring structures with simple side chains and with molecular weights of around 300. Some twenty-eight steroids have been isolated from the adrenal cortex. The sexual apparatus also secretes a variety of steroids differing only in minor structural details from each other and from the steroids of the adrenal cortex. A few of the same steroids are released both by the sexual apparatus and, to a lesser degree, by the adrenal cortex as well. Of the numerous steroids isolated, many at present have no known physiological function, although the action of others is now understood.[1,2,3] Thus, steroids with oxygen in the number 11 position on the carbon skeleton are concerned with the conversion of nitrogenous substances to sugar and the storage of sugar in the liver. Work of Dougherty and White[4] has indicated that the primary protein source for this gluconeogenesis is from lymphoid tissue. The injection of cortical extract or of corticosterone or of 17 hydroxy 11 dehydrocorticosterone into rats produces a disintegration of lymphoid tissue and a drop in the circulating lymphocytes. This is accompanied by increase of liver glycogen. Injection of pituitary corticotrophin results in similar effects but does not do so after adrenalectomy. Desoxycorticosterone lacking oxygen at the number 11 carbon is typical of the hormones concerned with salt and water balance in the body and has little or no effect on sugar metabolism.

In the course of metabolism many, but by no means all, corticosteroids are converted to 17-ketosteroids; i.e., those containing an oxygen atom at the number 17 carbon. 17-ketosteroids may be determined in the urine by micro methods.[5] In men 80 - 90 per cent of the urinary 17-ketosteroids are believed to be of adrenal cortical origin; in women probably 100 per cent come from the adrenal cortex. The 17-ketosteroids have thus been used as an overall method of assaying adrenal function in man and in 1940 when we began our studies this was the only practical method of determining human adrenal cortical activity. The work which I am about to report is the result of a number of studies in collaboration with Dr. Gregory Pincus and others of the staff of the Worcester Foundation. Nicholas T. Werthessen, Harry Freeman, Fred Elmadjian, Louise Romanoff, David Stone, and James P. Carlo have participated in various phases of the investigations. Our studies have been aided by grants from the G. D. Searle Company, the Office of Emergency Management, the Schering Corporation, the Memorial Foundation for Neuroendocrine Research, and the Office of Naval Research.

We were led to undertake our studies because it seemed likely that the adrenal cortex might be significantly involved in the development of fatigue in healthy young men. Adrenal insufficiency, due to Addison's disease and adrenalectomy in animals, is accompanied by lassitude, fatigue, collapse, and death, unless relieved by suitable adrenal medication. Selye's[6,7] studies of the alarm reaction had indicated marked adrenal involvement in animals subjected to acute stresses, such as injections of toxins, surgical insult, infectious disease, extremes of temperature, exercise, and anoxia. The importance of potassium in mechanisms of nerve conduction and central nervous function and the role of the adrenal cortex in potassium metabolism also suggested the possible involvement of the adrenal cortex in nervous fatigue.

In a study of a group of ninety-seven urine collections obtained from seven healthy young men taken at different times during the day when they were going about routine laboratory activities, we[8] found a diurnal rhythm of 17-ketosteroid excretion indicating a rise of approximately 60 per cent over the night rate of excretion the first hour after rising in the morning. This was followed by a general decline to night levels throughout the day. In subsequent tests involving specific stresses, this diurnal variation of our base line of excretion has been taken into account, and suitable corrections for time of day of control and of stress samples have been made.

That airplane flight itself causes an increased 17-ketosteroid excretion is demonstrated by data on two sets of pilots[8]: (1) flight officers on routine instructing duties at low altitudes, and (2) test pilots in experimental flights at varying altitudes. Urine specimens were collected from the pilots. Two samples were collected each day, a control sample and a sample covering the period of flight duty. For each period of flight duty a record of actual flying time was made.

Data were obtained from sixteen Army pilots for 152 training flights and a plot was made of the increased output over resting levels of 17-ketosteroids for the flight sample against the percentage of time that the pilot was airborne for each flight. A linear relation was obtained such that the greater the time in the air, the greater was the steroid output and the correlation coefficient was 0.978 with a P value of < 0.01. A repetition of this experiment carried out on 56 flights of seven Pratt and Whitney test pilots gave a similar result with a correlation coefficient of 0.922 $\pm < 0.01$. In the case of the test pilots whose flight operations were more stressful than those of the Army instructors about twice as much stress 17-ketosteroids were excreted on the average as a function of per cent time in the air.

Enhanced excretion of 17-ketosteroids was found to occur with a wide variety of stresses[9,10]. We found that the stress of taking both oral and written examinations as well as exposures to extremes of temperature increased 17-ketosteroid output. This increased output was not due to an increased output of urinary water since control experiments demonstrated independence of 17-ketosteroids excretion to diuresis induced by imbibing large quantities of water[10].

We mentioned that Dougherty and White had shown in animals decreased lymphocyte counts accompanying increased activity of the adrenal cortex and this change in the number of circulating lymphocytes has proved to be a useful tool in assaying adrenal function in man. During the past two years we have utilized in our laboratory other indices of adrenal function. Thus, Heard, Sobel and Venning[11] have made available a method for the analysis of urinary cortins based on the reducing properties of the ketol side chains of the steroids. Urinary uric acid we have also found to reflect adrenal function as an index of protein metabolism. Urinary sodium and potassium have also proved to be useful indices of the electrolyte regulators of the adrenal cortex. Table I shows data indicating changes of these six variables when 5 cc. of Upjohn's lipo-adrenal extract are injected into normal men.

Fatigue is a term in common use which has little precise meaning. In order to define fatigue for experimental purposes, it is necessary to obtain a measure of performance decrement. We were not interested in muscle fatigue in the ordinary sense, but rather in what might loosely be called mental or nervous fatigue, or the fatigue of prolonged psychomotor operations.

We accordingly designed a pursuit meter, consisting of airplane-type controls, in which a rectangular beam of light could be moved so as to cover a target[8]. Our target was a model airplane located some eight feet in front of the operator with two photo-electric cells in the engine nascelles of the model. The model was arranged at the end of a rod and activated by cams causing it to move in a random fashion; banking, rise and falling, and moving left and right at variable speeds. The operator followed the erratic movement of the target with his rectangular bar of light, endeavoring at all times to bracket both photo-cells simultaneously. Most operators reached a learning saturation usually in six to seven hours. Clocks scored continuously the percentage of time the operator could "ride the target", and counters recorded his errors. Pilots reported that this machine was about as stressful to operate over an hour period as was an hour of close formation flying in bad weather. When learning was complete, we usually encountered a decline in performance over an hour's run, and this decrement served as a measure of the pilot's fatigability.

Figure 1 shows the mean performance of a skilled operator in three runs on this machine[12]. This operator had previously had twenty-five hours of practice so that his learning was complete. For the first twenty minutes his oxygen supply was progressively depleted from room air to approximately 13 per cent, and for the remainder of the time he breathed air of this oxygen content (curve with crosses). The stress was thus a combination of pursuit meter operation and low oxygen. His performance in terms of the percentage of time he could ride the target is shown by the curve with the circles, in which his skill declines from 60 per cent to about 30 per cent in an hour and a half. The curve with the squares indicates a corresponding drop in the operator's lymphocyte count, which reflects the activity of the 11-oxygenated corticosteroids. The parallelism between performance and lymphocyte change is indeed striking.

If we dividedthe mean score of per cent time on target for the first half of a given run into the mean score of per cent time on target in the second half of the run, we obtain what may be defined as a fatigue ratio. If no decline in scoring ability takes place throughout the run, this ratio is unity. Fatigability over the entire run is thus expressed by some number between 0 and 1. For these particular data, the fatigue ratio as indicated in the figure is 0.803, and Figure 1 is typical of a number of experiments.

Accompanying the drop in lymphocytes, we have systematically found increases in 17-ketosteroid output, and this is shown by Figure (2). In this figure we have plotted the fatigue ratios of a number of experiments carried out with two skilled operators breathing air of the oxygen content shown on the abscissa. The numbers in the circle refer to the number of experiments per point. The runs were all of two hours' duration, and it is clear that the performance in the second hour declines appreciably for percentages of oxygen below 17 per cent. The curve described by the dotted line shows the stress output of 17-ketosteroids; i.e., the enhanced output of stress samples over control samples taken the same day and corrected for diurnal rhythm. Increasing altitude is accompanied by poor performance and increased 17-ketosteroid excretion[8].

We found marked differences in performance scores from man to man on our pursuit meter and also great individual variability in the stress output of 17-ketosteroids. Figure (3) shows the relation between the increased output of 17-ketosteroids due to pursuit meter stress and the mean error scores in the second halves of the runs for each of seven individuals, all of whom showed approximately the same scoring ability at the beginning of the run. The results of approximately ten experiments for each individual are averaged on this figure for each point. The pursuit meter used in this test embodied similar principals to that previously described and has been discussed elsewhere[8]. In this test it is clear that the large excretors (G and F) for example, make high error score in the second half of the run. The most efficient performers (A and B) show very low output of stress 17-ketosteroids. If the error scores are a result of the stress involved, then the 17-ketosteroid increases represent a quantitative measure of the stress response.

The fact that low concentrations in 17-ketosteroid output are displayed by the more stress resistant individuals cannot be interpreted as a sign that these people are less active in output of steroid hormones than are others. It may be that in the more efficient group of performers the adrenal hormones are metabolized differently and do not appear in the urine as 17-ketosteroids. It is also possible that the good performers are not as much stressed by this test as others and do not as much need to call on aid from their adrenal mechanisms. At the time this work was done, no other index of adrenal cortical function was available for our use.

In view of our findings that workaday stresses enhance the output of adrenal hormones, we became interested in investigating stress responses in psychotic patients who, as a group, have most notably failed to meet the stresses of life and who have developed bizarre and unacceptable modes of behavior as a consequence. Facilities for such studies have been available to us at the Worcester State Hospital and we have accordingly during the past three years examined the adrenal cortex physiology in schizophrenic patients. Schizophrenia develops slowly as a result of life's batterings. Why some people develop this disease and others do not is a mystery since often it occurs in individuals whose life stresses do not seem to be impressively great. Some people are evidently more vulnerable to the disease than are others.

We have accordingly compared the adrenal responses of about fifty schizophrenic patients at the Worcester State Hospital with those of a corresponding group of normal people. Our stresses were the prolonged operation of an airplane type pursuit meter, exposures to heat, to cold, to anoxia, and the taking of standard psychological tests. Getting up in the morning is also an adrenal cortex stress since in normal people there is a 50% rise in hormone output above the sleeping level during the first two hours after waking. While some of this work has been published[3,12,13,14,15] much of it has not been and I should like at this time to present some of our recent results.

What we found was a striking difference in the stress responses of our patient group as compared to the normal people. The psychotic patients for the most part show little or no increased hormone production with stress and thus fail in their emergency adrenal responses so characteristic of the rest of us. This we found to be true not only of schizophrenic patients but also of other types of psychotic patients suffering from acute depressions. In contrast to the psychotic patients we have found that patients who are not insane but are suffering from the milder psychoneuroses tend to display either normal or abnormally large adrenal stress responses.

The over-all 24-hour release of adrenal cortical hormones in the psychotic patients is not especially different from that of normal persons in the resting unstressed state. These substances are apparently synthesized in the patient's glands and seep into the blood stream. What is primarily defective in the patient is his ability to increase his hormone output in response to environmental needs and this appears to be the most clear-cut physiological difference distinguishing psychotic patients from others that has yet been found.

The adrenal cortex has no nerve supply and is only indirectly under the control of the brain. Its activity is regulated by one or more protein hormones adrenocorticotrophin (ACTH) from the anterior lobe of the pituitary. If adrenal hormones are not released by stress, the defect might be either in the adrenal cortex or in a failure of the pituitary to stimulate it, or finally in a failure of the brain to activate the pituitary.

A recent series of experiments on groups of patients and normal controls indicate that the defect in the patients lies primarily in a failure of ACTH to excite the adrenal cortex. This unresponsiveness to the pituitary hormone is shown by injecting adequate doses of ACTH in patients and normal persons. The latter all respond to the ACTH by releasing adrenal cortical hormones but most of the patients fail to show this increase in response to the same dose of ACTH that is effective in normal persons.

Tables 2 and 3 show changes in the six variables listed in table 1 as indices of adrenal function for pursuit meter stress and for ACTH injections in patients and in normal controls.

One of the substances important to the body's economy that is regulated by the adrenal cortex is potassium. Potassium in nerve tissue is an important agent in the conduction of nerve impulses. Following stresses that release adrenal cortical hormones, in normal people we find interesting shifts of potassium between tissues and body fluids (tables 2 and 3). Thus an hour's operation of a pursuit meter or the injection of 25 milligrams of ACTH will temporarily increase the output of urinary potassium some 100% in normal men. In schizophrenic patients these same procedures usually result in no increase whatever in urinary potassium output. If movements of potassium are important in controlling normal brain function, their repeated failures with stress may result in the formation of abnormal pathways for conducted nerve impulse in the brain so that in time inappropriate and bizarre behavior patterns may result. This hypothesis, concerning the physical basis of insanity, of course, requires further investigation.

It is unlikely that any one factor can be regarded as the "cause" of a psychosis. It may be that chemical deficiencies such as we have been discussing make some persons more vulnerable to the stresses of living than others. Such persons may never become psychotic if their lives present few problems, but under more severe environmental stresses their physiological defects may result in brain malfunction with consequent disturbances in personality and in behavior.

Since presenting this paper at the ONR conference, we have obtained data on more patients and controls and have completed a statistical analysis of the results. These findings will be reported in detail elsewhere. Also since the ONR colloquium, several studies confirmatory of aspects of our work have appeared. Thus Cleghorn et al.[16] have found lymphocyte changes similar to those we have described resulting from psychomotor stress. Thorn et al.[17], quite independently, have used the measures of adrenal cortical function illustrated in our tables and report similar effects to those obtained by us on injecting ACTH into normal persons. Marks et al.[18] have also found lymphocyte changes in man similar to those we have elsewhere reported in connection with the stress of orally administered glucose. Finally, the reader is referred to reviews by Long[19] and by Sayers and Sayers[20] for descriptions of the numerous studies of adrenal responses to non-specific stresses.

Figure Legends

Figure 1. Data showing change in per cent lymphocytes and in scoring on the Hoagland-Werthessen pursuit meter at oxygen levels as indicated.

Figure 2. Fatigability and stress 17-ketosteroid output. For a discussion of the measure of fatigability used in this figure the reader is referred to the original publication.[8]

Figure 3. The 17-ketosteroid excretion in seven male subjects in relation to pursuit meter scoring in the second halves of two-hour runs. The mean error score for the second hour is plotted against the excretion above resting levels for sixty-nine experiments. (Approximately 10 tests per man). Note poor performance with excessive 17-ketosteroid output.

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TABLE I.

Effects of Injection of 5 cc. of Upjohn's ACE

	Mean % change 1.5 hrs.	2.5 hrs.	No. normal men
17-Ketosteroids	92.0	58.8	13
Lymphocytes	-12.9	-11.5	15
Uric Acid	58.5	23.2	12
Cortin	43.9	16.5	11
K (urine)	38.0	45.7	12
Na(urine)	86.1	24.1	11

Table 2 - Per cent change following an hour's pursuitmeter operation beginning at zero hour - compare lines 3 and 5.

Variable	lymphocytes				urinary uric acid			urinary cortins			urinary 17-ketosteroids			urinary sodium			urinary potassium		
1. Time in hours	0	1½	2	4	0	1½	2½	0	1½	2½	0	1½	2½	0	1½	2½	0	1½	2½
2. Number of normals	16	16	16	16	15	15	15	14	14	14	12	12	12	13	13	13	12	12	12
3. Values for normals	100	86	91	102	100	156	113	100	113	107	100	210	155	100	210	148	100	218	170
4. Number of patients	23	23	23	23	23	23	23	18	18	18	23	23	23	14	14	14	14	14	14
5. Values for patients	100	99.4	94.9	101	100	88	85	100	98.6	100	100	87	88	100	83.4	82.7	100	97	90

Table 3 - Per cent change following intramuscular injection of 25 mg. ACTH at zero hour - compare lines 3 and 5.

Variable	lymphocytes				urinary uric acid			urinary cortins			urinary 17-ketosteroids			urinary sodium			urinary potassium		
1. Time in hours	0	1½	2	4	0	1½	2½	0	1½	2½	0	1½	2½	0	1½	2½	0	1½	2½
2. Number of normals	10	10	10	10	9	9	9	7	7	7	7	7	7	9	9	9	10	10	10
3. Values for normals	100	87.8	75.3	73.2	100	142	149	100	144	148	100	92	187	100	164	162	100	187	209
4. Number of patients	13	13	13	13	12	12	12	10	10	10	10	10	10	10	10	10	10	10	10
5. Values for patients	100	102	97.3	87.9	100	97.7	115	100	104	117	100	80	105	100	87.1	90.6	100	100	115

Dr. MacKenzie: With regard to the adrenal cortex we must have a large number of men. Repeating this work on two or three men is a waste of time. It is the one hope at this time that there is some quantitative means of measuring fatigue with the diets controlled.

Dr. Hoagland: It was not possible to control the diets. These people had had nothing to eat since 7:00 A.M. on the day before.

Dr. Dill: According to these figures the urine volume of the psychotics would be four liters per day.

Dr. Hoagland: These patients do put out an exceptional volume of urine. It is surprising that they excrete that much salt.

Circulatory Aspects of Fatigue - Dr. Charles E. Kossmann

If stresses, compensations, and strains caused by fatigue on the circulatory system are to be evaluated, the several functions of the system must be considered separately. For purposes of discussion some of these may be listed as:

(1) The supply of oxygen to the tissues
(2) Maintenance of blood pressure
(3) Maintenance of local heat and general heat by variations in circulation to, and hence radiation from, the skin.

"Fatigue" is used in the physiologic sense that any one or combination of these functions is impaired. It would appear that fatigue thus defined might be brought about in one of three ways: (a) the efficiency of the heart or of the blood vessels may be impaired by disease or by as yet unmeasured physiologic deterioration (see below); (b) the demands of the tissues involving these functions may be in excess of the physiological capacity of the system (e.g., syncope from prolonged strenuous muscular effort or from standing at attention for a long period on a hot day); (c) both a and b may occur together.

It must be apparent at once that stresses of the type which cause impaired function of the cardiovascular system are common in aviation. They include hypoxia, aeroembolism to a variety of organs, radial and linear acceleration, and thermal stresses either in the form of excessive heat or excessive cold. In all of these the circulatory compensations to the specific stress are enormous. Providing that the organism as a whole is not destroyed, once the stress ceases to act the circulation recovers completely. The one notable exception is seen with local thermal stress of such extent as to cause a burn or frostbite.

These stresses, which are really physical or environmental, cause not only physiological compensations and strains on the circulation, but if permitted to act for long enough periods of time or at frequent enough intervals, can also cause fatigue defined as an impaired integrative action of the organism as a whole. These physical stresses in military aviation are for the most part controlled or minimized by methods which are well known to all of us.

Even with full control of all the physical stresses involved (except vibration), fatigue of the flyer as a whole personality is an entity when flights are long or hazardous. The causes for this clinical syndrome must be sought more often in other than the physical stresses mentioned.

The psychological stresses have been dealt with expertly earlier in this conference. However, it might be worthwhile to add that anxiety is latent in all men and fatigue simply activates it. Clinically, and especially in military aviation, a differentiation must be made between anxiety as a symptom of fatigue, and fatigue as a symptom of anxiety. The differential diagnosis is usually not too difficult for the trained flight surgeon if adequate consideration is given to the patient's psychic makeup and background, the nature, intensity and duration of the psychological stress involved, and the clinical manifestations. If the latter should include such signs and symptoms as precordial pain, palpitation, dyspnea on effort, giddiness or dizziness, cyanosis of the extremities, cold clammy skin, syncope on standing or tilting, labile blood pressure and labile pulse rate certain somatic possibilities must be considered. These include organic disease of the heart itself; generalized infections some of which, such as influenza and gastrointestinal infections, notoriously impair vasomotor function; and the cardiac anatomy. By the last is meant particularly the size and position of the heart in the chest. It is the impression that the syndrome of vasomotor instability in response to a strong emotional stimulus, or its chronic clinical counterpart known as effort syndrome or neurocirculatory asthenia, are more common in subjects with a heart which is somewhat smaller than normal and which has an anatomical and electrocardiographic position in the chest which is vertical. With an investigation of such factors as these it may be possible to understand predisposition to certain circulatory symptoms in response to a psychological stress.

But the importance of psychological stresses in inducing fatigue are well known. In the fatigue of flight they are numerous. Most of them can be eliminated with better equipment and better training of crews; some, such as various flying hazards, can be reduced; but the basic one, namely flight itself, must always be present, except, of course, in robot flight.

That leaves physiological stresses of fatigue on the circulation to be considered. It is this aspect of the problem which is most nebulous. "Physiologic deterioration" of the cardiovascular system in fatigue, when all the physical and psychological stresses are controlled, is an assumption based on the knowledge that any organ can be worked to the point of exhaustion. The detection of such physiologic impairment short of exhaustion is elusive probably because the methods available for study of the circulation are not sufficiently refined, and because the adaptations and compensations are so excellent. The approach to the problem is made more difficult by ignorance of the fact that the disturbance, if it does exist, may be mediated through the brain (cortical control of automatic functions), or the metabolism of the entire body or of some particular organ. In the chronic fatigue of civilian life, for example, there may be a variety of cardiovascular manifestations such as bradycardia, hypotension, premature systoles, dyspnea and palpitation on effort, giddiness on standing or walking, and abnormalities of the electrocardiogram. Accompanying these there may be a low basal metabolic rate or a low grade anemia, suggesting that the circulatory disturbance may be secondary rather than primary. With this syndrome there are usually the well known symptoms of loss of memory, inability to concentrate, irritability, and insomnia. Oddly, a few of these patients may not complain of fatigue but perhaps this is a refusal on their part to admit that the symptom exists when it in truth does. This chronic fatigue or "staleness" is encountered in aviation as elsewhere, and its clinical detection is not too difficult. But as mentioned, the nature of the changes in the circulation, and their relative importance in the entire picture are obscure.

Possible <u>tests of fatigue</u> of the circulation revolve about the efficiency of its several functions. In furthering our knowledge it would be wise to differentiate between the results obtained in acute fatigue and in chronic fatigue. Unfortunately a good number of the available tests depend on aerobic work done by the individual. This immediately brings in the factors of cooperation and motivation, and the efficiency of the respiratory system.

"Cardiac output" can be measured in a variety of ways, all of which have certain objections. The one in vogue at present is the cardiac catheterization method utilizing the Fick principle. Recent investigations make it likely that in the near future other simpler devices will be available (impedance plethysmograph, radioactive isotopes). As applied to fatigue it would be desirable to measure the maximal stroke volume and maximal cardiac output and cardiac index in response to maximal work. The assumption is that in fatigue maximal output would be smaller than normal, for in disease of the heart, a type of fatigue or diminished reserve, the stroke volume cannot be increased in response to work to the same extent as the normal.

"Maximum oxygen debt" is the excess oxygen used during the recovery from work and reflects probably a delay in the oxidative processes during the adaptive period to work. From data available there is probably no relation between maximal oxygen debt and fatigue but there may be between fatigue and the speed of accumulation of the debt. The early phases of recovery depend on oxygen transport, and it is this phase, if any, which may be delayed in fatigue of the circulation.

"Oxygen saturation of the blood" though easily and quite accurately determined with newer modifications of Millikan's oximeter, is not likely to be altered much in fatigue. More promising, perhaps, is the form of the "oxygen dissociation curve" which is known to shift to the right in heart disease and with exercise, a process which favors the tissues but which makes oxygen saturation of the blood in the lungs less facile. The curve should be studied in fatigue.

"Heart volume" would seem to be a measurement which might throw light on the completeness of emptying of the heart. It is measured by frontal and sagittal orthodiagraphy utilizing Rohrer's formula. The method is only moderately reliable but could be improved with better radiographic equipment now available. Immediately after exercise the heart volume is smaller despite the greater stroke volume at the time. The inference is that more complete emptying occurs than at rest. That the ventricles do not completely empty with each systole has been amply borne out by angiocardiographic and radiocardiographic studies. These phenomena, at least, give a lead for further study. Possibly in fatigue even less complete emptying occurs than in the normal subject.

"Peripheral venous pressure" is increased by exercise in fatigue of the heart caused by disease. In the healthy subject exercise at first increases then decreases the pressure in the vein provided that there is no local obstruction. The determination of peripheral venous pressure and possibly of right auricular pressure may show a trend in fatigued as compared to physically fit subjects.

Post-exertional hypotension or syncope is fairly common in normal subjects. A "tilt table test" with or without exercise may prove of value in determining fatigue of the peripheral vasoconstrictor mechanisms.

The "electrocardiogram" is known to show variations in the syndrome described above as chronic fatigue. These changes are manifested largely in the recovery process (T wave) which is quite sensitive to a variety of ionic changes, in particular hypopotassemia and hypocalcemia. More complete information will be obtainable as sagittal as well as frontal electrocardiograms and vectorcardiograms are recorded. The changes in fatigue that may be found may give a lead to further biochemical investigations.

"Pulse rate" and "blood pressure" at rest or in response to exercise will probably not yield any useful information in fatigue because both of these measurements are so greatly affected by the emotions. For this reason the Schneider Index was dropped from the physical examination for flying during the last war, for it was not a true measure of physical fitness. If anything, it was a crude measure of emotional or vasomotor stability, although one's score could be improved by physical training.

Methods are now available for studying the "local circulation" and metabolism of such organs as the liver, the kidneys, the lungs, and the brain. In addition, local circulation to the extremities may be studied by plethysmography. The methods can bé used in the quest for circulatory abnormalities in these organs in fatigue.

There are certainly many other methods that could be used but those mentioned above are regarded as most likely to give information on the elusive, circulatory aspects of fatigue.

In <u>conclusion</u> it may be stated that the stresses on and compensations of the circulation resulting from the physical and psychological factors known to cause fatigue are fairly well understood, and can be quite satisfactorily handled. There are believed, however, to be additional physiological alteration of the circulation in the syndrome which have escaped detection probably because methods for studying them are not sufficiently sensitive. Some methods which may be used to acquire further information on circulatory aspects of fatigue have been listed.

<u>Dr. Emerson Day</u>: We have increasing evidence of objectivity in the study of fatigue. Up to now we have had an attitude of defeatism about doing anything objectively about fatigue. We must control factors of motivation. Attempts to evaluate flight personnel by giving anoxemia runs under controlled factors, showed that oxygen saturations varied from 87 to 59 per cent from person to person. We felt that this variation was related to a personality factor.

Dr. Riley: Chronic fatigue is distinctive and is quite different from the fatigue of muscular exercise. Circulatory factors are predominant in muscular fatigue. The amount of work which the right heart can do is a deciding factor in how much exercise a person can do.

Dr. MacKenzie: There is a parallel between chronic fatigue and anoxia. It seems that the same syndrome shows a blocking of all chemical reactions and might have a block concerned with electron transfer even with plenty of oxygen available. There might be a chance of obtaining drugs that might overcome this block.

Respiratory Factors in Fatigue - Dr. F. G. Hall

It seems to me that there are two divisions; fatigue of breathing and fatigue of anoxia. Then there could be three different levels of compensation. If the individual changes his breathing rate, this will compensate to some degree. The second level of compensation would be with training or acclimatization. The third level of compensation would be hereditary factors which are fixed in the body, such as, vital capacity, and different types of hemoglobin as in different species.

In the fatigue of breathing we can measure the total amount of energy involved as 7/10 to 6 per cent actual energy used in the work of breathing. So this is very small and there would not be much fatigue involved in the mechanics of respiration. There is no good way to measure this fatigue either. I have been trying to think of any measurement we might have of fatigue. We can record breathing patterns and we see no change with fatigue. We will get a sigh after several hours. Pilots complain of using oxygen equipment because it tired them but actually, this must be very slight.

With regard to anoxia, some southern football teams have been using oxygen to relieve fatigue after the game is over.

With regard to oxygen debt, if we measure the basic oxygen usage and then produce oxygen debt, the latter is not a personal characteristic.

Dr. Pappenheimer: When you use oxygen equipment the work of breathing does become important. Nobody has measured metabolism going into breathing. We could do this by breathing a mixture of oxygen and carbon dioxide. At a rate of 40 liters per minute it becomes uncomfortable but with exercise you do not feel this discomfort.

Fatigue Tests - Dr. John C. Flanagan

In discussing fatigue tests it seems wise to adopt a broad definition of fatigue which is in line with the general orientation of the materials presented in this conference. Accordingly it is proposed that under the heading fatigue tests, all methods of measuring strains due to stresses both physical and mental (including emotional) be included.

Studies of U.S. Air Force and of commercial airline pilots have shown that in addition to hours of continuous flying and hours since the last sleep period other stresses such as turbulence, traffic, formation flying, enemy opposition, closed in airports, and equipment failures also contribute to feelings of fatigue. Because of the unusual demands on the pilot it seems of special importance to obtain precise measures of his fatigue following certain types of experience in order that schedules and missions not be adopted that require him to perform when he is in a fatigued condition. The types of changes which are measured by various fatigue tests will be discussed under five major headings. These include (1) the impairment of actual performance, (2) the impairment of the ability to perform, (3) changes in physiological or bio-chemical characteristics, (4) changes in activity level of muscles (electrical potential), (5) changes in attitudes and subjective reports of feelings.

1. The impairment of on-the-job performance. This type of impairment relates to the decrement in ability to perform the actual task of the worker being studied. If the task is a simple one requiring a single group of muscles, the reduction in effectiveness can be easily observed. For example, a lifting or placing job which makes fairly heavy demands will soon produce an easily discernible decrement in ability to perform the task. In a similar way, circulating and respiratory effects which effect the whole body may be measured resulting from heavy demands on these systems. Mental tasks may be similarly studied from the point of view of decrement in actual performance. Also performance of complex tasks may be impaired by continuous activity.

It should be noted that this type of measure is not of practical value for most types of activities since decrements which occur can usually be compensated for if the individual is provided a special incentive. Only extreme stresses produce strains which cannot be nullified by increasing the individual's motivation.

2. The impairment of performance on standardized tasks. This type of impairment measure consists of a standardized task with respect to which work decrements are studied. They may involve various functions as in the case of the on-the-job performance measures. These standardized tests such as the bicycle ergometer, the cardiovascular tests, sensory acuity tests, mental tests, and complex tests are subject to the same disadvantage as the measures previously discussed. A number of tests have been found to show a decrement after prolonged activity of various types. These include steadiness, pursuitmeters, critical frequency of ficker fusion, cancellation, addition, coding, and reasoning tests. Probably the most successful of these are the complex pursuitmeters such as the tri-dimensional pursuitmeters and the complex reasoning tests.

3. Changes in physiological of bio-chemical characteristics. The great influence of incentives on short tests or behavior on the job during short periods of observation and the ability of the subject to perform practically as well after what seem like extreme stresses in the form of continued activity and sleep deprivation have intensified the interest in obtaining an objective basis for measuring fatigue. Numerous measures have been studied. These have included cardiovascular measures, blood counts and urine analyses. Although most of the evidence from these studies has been negative, there have been reports of positive findings with respect to lymphocyte counts and changes in the output of the 17-ketosteroids. Further research appears desirable in this field.

4. Changes in the activity level of muscles (electrical potential). Another approach to the problem of obtaining an objective measure is that of the measurement of changes in the electrical potential of muscles. Recent studies reported at this conference indicate that by using muscle potentials over the eye a measure of alertness in terms of the activity level of muscles can be obtained. Much more research is necessary to establish the relationship of such activity levels to fatigue. However, this appears to be a promising technique and worthy of further investigation.

5. Changes in attitudes and subjective reports of feelings. There are some who favor reserving the word fatigue for use only with reference to the concept of feeling of fatigue as contrasted to freshness. If the individual reports that he feels tired, worn out, or exhausted he is considered to be fatigued, whereas if he states he is alert and fresh he is presumed not to be fatigued. Various studies have shown that subjective reports of this type may vacillate from one extreme to another without any apparent adequate change in the stress imposed. Indirect tests of attitudes and feelings have also been tried without much success. Some have stated that the only available method is to rely on the clinical judgment of an expert to tell whether and to what extent an individual is fatigued.

It is apparent that very little progress has been made in developing satisfactory fatigue tests. The definitions and descriptions of fatigue should be clarified and expanded to increase the effectiveness of future work in this field. Probably the most striking conclusion which can be drawn from present tests is the remarkably rapid recovery of the human being from what appear to be very serious and prolonged stresses. The individual seems to be able to pull himself together to do almost any brief task at close to his maximum efficiency level even after prolonged periods of continuous activity of a relatively strenuous sort. Perhaps a fruitful approach to the measurement of fatigue can be obtained from measures of the effort required to carry on a task following periods involving various types of stresses. It is known that the tasks can be done. However, it may be possible to measure the increased stress on the individual which is necessary to maintain his standards of performance on the task. It is recommended that on so important a topic as fatigue measurement continued effort should be expended in spite of the meager gains resulting from past research.

Dr. Maison: We must measure fatigue on the job where the man is to be fatigued. We haven't had enough subjects. There is a great danger in selection for fatigue liability.

Dr. Masland: I wish to emphasize the difficulty of measuring fatigue. The problem is very much the same as that of the anoxia problem which was first attempted to solve by selection of men not susceptible to anoxia and then when that was not possible, by an attempt to remove the stress. We should try to remove the stress as far as fatigue is concerned by proper sleeping accommodations, in-flight feeding, etc. while the men are flying.

Summary of the Program on Fatigue

Dr. Bronk: The type of stress associated with danger isn't going to be a factor in ordinary life. Few people are interested in what they have to do to survive. How is this going to effect the physiological and psychological reactions of the people? One thing we should learn from the Services is that there is more to medicine than the treatment of people that get past a plateau and down the other side. The armed services must handle people so they can be effective. This is not the case with the civilian physician except the psychiatrist. Howard Rusk has emphasized the idea of considering the patient as a whole and keep him from being ill. Symptoms of fatigue are really secondary symptoms of physiological state and the effect of mental outlook.

Colonel Kennard: This is a problem of a study of the man of the job. It has been suggested that we set up a program on a basis to study fatigue in long-range fighters. Colonel Benson says that we are not ready for this because we do not know what to study.

As far as selection is concerned it is not impossible to set up some standards of selection. We might set up some projects right at the fields.

If a man is in good condition he can still make a landing after a long flight but he has a lack of efficiency for several hours.

Dr. Fenn: We have some new methods of attack, such as, the biochemical ones and we hope there will be further investigations along these lines.

General Armstrong: In the study of the circulation, there may be other leads. Perhaps the low blood pressure leads to fatigue. The high-powered man usually has a high blood pressure. In middle life we have cardiac failure. These might tie in with fatigue.

We do not have the personnel and facilities to carry out the work but would be happy to make facilities available to scientists if possible.

Dr. Bronk: We cannot hope for a specific program of work. We can only discuss and exchange ideas and relate our own work to these problems. We wish merely to make an application to the specific problem. We do not desire a formalized program of attack and if we had one it would not work.