OUTLINE OF PRESENTATION FOR SYMPOSIUM ON ENGINEERING ASPECTS OF SPACE MEDICINE

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ASPECTS OF HUMAN RESPIRATORY PHYSIOLOGY PERTINENT TO SPACE ENGINEERING

I. Introduction: Respiratory and circulatory systems compensate for the long diffusion paths in larger animals. Effects of variation in gravity are not all predictable and may be extremely subtle. Chemical activity [proportional to partial pressure] of respiratory gases in the cells is the important property.

II. Composition of inspired gas.

General difficulties of determing detrimental effects.

A. O_2: Body adapts remarkably, but there are definite upper limits, and growing evidence of more strict lower limits.

B. CO_2: Again body can adapt, but there are definite upper limits.

C. Inert gases: Toxic effects are produced at higher pressures. Presence of an inert gas in alveoli needed to prevent atalectasis.

III. Respiratory function on lungs divided for discussion into four steps.

A. Mechanics: considering lung as bellows; normal values.

B. Distribution of exchanging blood in relation to gas flow:

C. Diffusion exchange of gas between alveolar air and capillary blood:

D. Circulation of blood through capillary bed of lungs and thence to tissue capillary beds: normal values.

A. Mechanics of respiration

1. Normal physiology: diaphragmatic action: pleura and intrapleural pressure: Spirometry and lung volumes: Airway resistance: Compliance

2. Possible effects of changes in gravity

a. change in lung volumes

b. change in airway resistance

B. Distribution of blood and gas flow

1. An important problem: A major dysfunction in disease: Extreme case with all blood flow to one lung and all gas flow to the other. Ratio of alveolar ventilation to capillary blood flow is the important factor.
2. Concept of respiratory dead space as wasted ventilation experimentally hard to measure. May have same effect on gas exchange as non uniform ventilation blood flow.
3. Several known regulatory mechanisms to maintain a balance between capillary blood flow and alveolar gas ventilation at the microscopic level.
4. Effect of space flight on distribution problems: Increased gravity produces extreme distortions: Decreased gravity will alter mechanical balance in lungs.

C. Circulation: discussed mainly elsewhere.

1. Pulmonary circulation is low pressure and more susceptible to changes in surrounding pressures, particularly intrapleural and atmospheric.
2. O_2 carried in blood bound reversibly to haemoglobin: CO_2 as bicarbonate.
3. Hydrostatic pressure differences in living lung limits gravitational force man can tolerate.

IV. Control of respiration.

A. Effect of arterial P_{CO_2} and pH on medullary respiratory centers.

B. Effect of arterial Po_2 on the chemoreceptors in the aortic arch and bifurcation of the carotid.

C. Cerebrospinal fluid pH and Pco_2.

D. Reflexes and sensation from elsewhere in the body.

E. Temperature

F. Higher centers in the central nervous system.

G. Possible derangements with changes in gravity. In zero G, reduction in sensation may lower respiratory minute volume to dangerous level, particularly during sleep.

V. Self cleansing actions of the lung

A. Cough: expells larger bodies from upper airway. Ineffective in lower airways.

B. Mucus sheet: propelled by the rythmic beat of cilia from the respiratory bronchiole to the pharynx. Effects of changes in gravity on this system are unknown. Extremely important in removing finer particulate matter from the lung.

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Outline of Presentation for Symposium on Engineering Aspects of Space Medicine,

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Research aspects of cardiorespiratory physiology as applied to space

Introduction:

A. Definition of research

A disciplined effort to increase knowledge of any aspect of human understanding

1. Methods of approach applicable to biomedical research

a. A productive approach is to study reactions of a system to a reproducible degree of stress, transient or maintained.

B. Research aspects of space flight in relation to cardiovascular physiology

1. Relation to aerospace medicine and physiology

Space physiology and space medicine are concerned chiefly with man's reactions to the stresses associated with flight. Hence these fields present multiple opportunities for research concerning physiology of the organ systems susceptible to these stresses.

2. Conduct of such research

a. In actual flights

1. Controlled experimentation difficult

2. Recording problems - gradually being overcome

b. In simulators designed to reproduce the various stresses of space flight

1. Controlled experimentation more easily attained

2. Recording problems less difficult

c. Non-simulatable stresses

1. Major one, sustained zero gravity, cannot be simulated on earth. Consequently its effects can only be studied during space flight. The opportunity to study the cardiovascular and respiratory

effects of prolonged exposure to a zero gravity environment is unique to space flight.

3. Examples of stresses associated with space flight which can be simulated on earth
   a. Zero atmospheric pressure
   b. Accelerations associated with launch and re-entry phases of flight or flight maneuvers
   c. Others
4. Specific research aspects in relation to cardiorespiratory physiology
   a. Cardiorespiratory reactions to acceleration will be discussed in particular since it is in my field of interest and knowledge.

C. The human centrifuge as a tool for research in cardiorespiratory physiology
   1. Description of human centrifuge
   2. Applications in cardiorespiratory research
      a. Control of blood pressure

         Positive acceleration can be used to produce sudden decreases in arterial pressure at head level of any desired degree. Study of the reactions of the cardiovascular system induced in this manner to elucidate circulatory physiology has been only partially exploited.
      b. Alterations in cerebral and retinal blood flow

         Positive acceleration can be used to produce temporary reproducible degrees of stagnant anoxia of the retina and brain of conscious normal human beings and hence offer a potentially fruitful field for study of the interrelationships of the level of consciousness, electrical activity of the brain and retina, arterial pressure at head level and blood flow to these areas.
      c. Alterations in pressure relationships and ventilation-perfusion ratios in the lungs

The low pressure pulmonary circulation is particularly susceptible to hydrostatic effects produced by acceleration.

The pulmonary system requires large air-alveolar membrane-fluid interphases for proper function.

Because of the great difference in specific gravity of air and blood, unavoidable regions of severe hydrostatic pressure imbalances result at the air-alveolar membrane interphases due to the multiplication in weight of the thoracic contents during exposures to increased levels of acceleration. Consequently the functions of the pulmonary system are very susceptible (perhaps more so than any other of the vital bodily processes) to malfunction due to acceleration.

Temporary obliteration of air containing alveoli (atelectasis) in the dependent portions of the lungs can be produced during and following exposures to acceleration such as encountered in the launch and re-entry phases of space flight. Large arteriovenous shunts occur in these regions of the pulmonary circulation and cause a reduction in the amount oxygen carried by arterial blood.

D. Feasibility and safety of such research

1. Studies of tolerance levels of man to various levels and types of acceleration carried out in multiple laboratories in this and other countries have demonstrated that under properly controlled conditions, the afore-mentioned alterations can be produced with safety and without demonstrable permanent sequelae.

   It is believed that this means of producing temporary severe alterations in the function of various organ systems of intact conscious individuals offers a valuable means for the further elucidation of their physiology.

E. Need for electronic data-processing and computation

1. Because of the multiple inter-related variables involved in such studies, use of electronic data-processing methods seem practically mandatory for full exploitation of the possibilities.

2. Description of system developed for this purpose

   a. Applications to other biomedical problems

PHYSIOLOGICAL ASPECTS OF WEIGHTLESSNESS

James P. Henry, Ph.D.

I. General

   A. Background

   B. Description of sensations in weightlessness

II. Sleep

III. Vision

IV. Position sense, equilibrium, and coordination

V. Alertness

VI. Cardiovascular Deconditioning

   A. Mechanisms

   B. Effects (Tilt table studies and general observations)

   C. Prevention

VII. Summary

Engineering Aspects of Space Medicine

Special Senses

John Lott Brown, Ph.D.

I. INTRODUCTION

If man is to play more than a passing role in space, his sensory capabilities and the demands which may be imposed upon them must be understood and evaluated. All of the information which he will receive on a space mission will be provided by his senses. It is the purpose of this presentation to review current knowledge of how the more important sensory modalities function and how they contribute to our perception of the environment.

II. VISION

The sense of vision will probably be the most important of all the senses to an astronaut. A major part of this presentation will therefore be devoted to a detailed consideration of the visual sense.

A. The Appropriate Physical Stimulus for Vision.

1. The visible spectrum: Electromagnetic energy in the range of 370 to 760 millimicrons.
2. Sensitivity of the visual detector: 2 to 7 quanta delivered within 0.1 second.

B. Range of Response.

1. Adaptation. Variable sensitivity of the retina permits adaptation to luminances over a range of greater than 1,000,000:1.
   a. The mechanism of adaptation. Primarily a neurological rather than a photochemical process.
2. Problems associated with extremes of illumination.
   a. Threshold stimulation.
   b. Excessive illumination and flash blindness.

C. Spatial Resolution and the Detection of Form.

1. Anatomy of the retina and visual pathway.
   a. The number of retinal receptors.
      (1) Rods: 120,000,000
      (2) Cones: 5,000,000 to 7,000,000
   b. Nerve fibers in the optic nerve pathways. Currently accepted number of fibers is approximately 1,000,000 although recent evidence suggests that there may be more. In any case, there are insufficient fibers to provide for direct connection of more than a very few of the retinal receptors to the brain.
2. Retinal interaction.
   a. Concentric arrangement of receptive fields with inhibitory and excitatory regions.
   b. A neurological mechanism for the enhancement of contour.
   c. Demonstration of perceptual phenomena which may be mediated by mechanisms of retinal interaction.
3. Cortical information processing.
   a. Specialized cells for perception of line elements
   b. A mechanism for the recognition and recall of complex forms
   c. Demonstration of perceptual phenomena which may depend upon cortical information processing.
4. Limitations of visual acuity related to experiences of astronauts.

D. Temporal Response Characteristics of the Eye.
   1. Critical duration of stimulation: 0.01 to 0.1 second.
   2. The visual system as a differentiator.
   3. Repetitive stimulation and applications of harmonic analysis.

E. Color Vision
   1. Trichromatic theory
      a. The existence of three specialized color receptors.
   2. Opponents processes
      a. Evidence from human vision for opponents processes.
      b. Neurophysiological support for opponents processes.
   3. Demonstrations of phenomena which support current theories of color vision.

F. Depth Perception

G. Applications of the visual sense on space missions.

III. HEARING

A. The Appropriate Physical Stimulus.
   1. Compression wave in an elastic medium.
   2. Need for artificial communication links in outer space.

B. Range of Response of the Human Ear.
   1. Frequency: 10 to 20,000 cycles
   2. Power requirements: 10^{-16} watts/cm^2 to 10^{-3} watts/cm^2
   3. Problems associated with extremes of sound power.

C. Temporal Response Characteristics.
   1. Adaptation. High speed adaptation of the auditory system.
   2. Temporal analysis of complex signals comprised of several frequencies.

D. Review of Anatomy of the Auditory Mechanism.
   1. The basis for mechanical transmission of sound to the inner ear.
   2. The cochlea and how it receives the energy of auditory stimulation.

E. Neurophysiology of Hearing.
   1. Neural interaction dependent upon frequency of stimulation
      a. Frequency sharpening.
   2. Binaural effects and sound localization.
   3. Corticofugal fibers and their possible relation to attention.

F. Pattern Recognition in the Realm of Sound.
   1. Analogies with the recognition of complex form in the realm of vision.
   2. Maximum utilization of band width.

IV. VESTIBULAR FUNCTION

A. The Anatomy of the Vestibular Mechanisms
   1. The semi-circular canals
   2. The utricles
   3. The saccules

B. The Appropriate Stimulus for Vestibular Mechanisms
   1. Linear accelération
   2. Angular acceleration

C. Ranges of Stimulation and Threshold Values

D. Illusions and Problems Which May be Associated with Space Flight.

V. THE INTEGRATION OF SENSORY INFORMATION

A. The Concept of Sensory Inputs in Various Modalities as Consciously Distinguishable

1. Basis for the concept
2. Validity of the concept
3. Inter-sensory illusions of orientation.

B. The Reticular Formation of the Brain Stem.

1. Its role in sensory integration

VI. OTHER SENSES

Their relevance in space flight.

A. Tactual
B. Gustatory
C. Olfactory

ENGINEERING ASPECTS OF SPACE MEDICINE

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Radiation Biology - Lecture Outline

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I The Interaction of Radiation with Matter

A. Initial physical and chemical events

1. Electromagnetic radiation - photoelectron and recoil electron production; relatively sparce production of ion pairs.

2. Particulate radiation - recoil protons, mesons, neutrons, etc.; secondary γ and x-radiation; dense ion pair production along particle track.

3. Formation of radicals in water: H, OH, H_2O_2, HO_2; breakage of chemical bonds; events occurring in 10^{-12} to 10^{-6} seconds.

B. Molecular and cellular effects of radiation

1. Modification of DNA molecule, enzymes, and other proteins; disruption of biochemical processes.

2. Induction of genetic change - gene mutation and chromosome aberration.

3. Cell death; modification of cell function.

C. Tissue and systemic effects of radiation

1. Proliferating tissues (blood forming, intestinal wall) - reduction or inhibition of cell division; depression in cell number and tissue function.

2. Non-proliferating tissues (liver, kidney, CNS) - persistence of damaged cells; absence of immediate evidence of injury.

3. Systemic manifestations of cell and tissue damage.

D. Miscellaneous factors

1. Time-intensity variables - reduced biological effectiveness by dose protraction and fractionation.

2. Relative biological effectiveness (RBE) - recognition of differences in biological effect due to pattern of energy transfer and ionization density.

3. Partial body exposure.

4. Chemical and bone marrow therapy.

II Human Radiation Biology

A. Acute radiation injury

1. Central nervous system injury - dose range 1000r and up - survival time less than one week; death from shock, fluid loss, hemorrhage, widespread tissue destruction.

2. Hematopoietic injury - dose range: 50r - 650r - sublethal to lethal; death in one week to two months; minimum lethal dose ca. 150r. Death from hemorrhage, infection, anemia.

3. Prodromal responses - nausea, vomiting for several hours to one day; fever, loss of appetite, diarrhea; minimum dose probably 50r for most sensitive - 250r probably will produce prodromal reactions in all persons.

4. Subacute injury - protracted recovery in survivors or sublethally exposed; temporary sterility.

B. Chronic or long term radiation injury

1. Reduced life expectancy - extrapolation from animal data suggests a non-linear response to single doses and an estimate of 15 - 20% (~ 6 - 8 years) reduction by 400r - 500r; more linear response expected from continuous low intensity exposure and an estimated loss of 1 - 2 days per r accumulated.
2. Leukemia induction - probability of leukemia occurrence: $1\text{-}2 \times 10^{-6}$/r/year for 15 - 20 years post-exposure for doses of 50r or greater.
3. Other malignancies - present evidence indicates increased death rate from gastric, pulmonary and skin cancer.
4. Cataract formation - linearly increasing probability above 200r - may approach 100% above 1000r.
5. Genetic damage - mutation rate for recessive visible genes: $5\text{-}25 \times 10^{-8}$/r/gene; recessive lethal mutations per gamete: $1\text{-}20 \times 10^{-4}$/r.

III <u>Determination of Radiation Safety Standards in Manned Flight Operations</u>

A. Present ICRP and NCRP maximum permissible dose (MPD) values generally unacceptable

1. MPD's set for potentially large populations at risk - not small flight crews.
2. MPD's set to hold biological hazard to occupationally exposed group as "negligibly small".
3. MPD's set for assumed career of about 50 years.
4. Philosophy of standards inconsistent with problem of multiple risk situation of manned flight.

B. Radiation protection primarily a matter of "acceptable degree of risk" vs "mission failure"

1. Risk primarily a function of acute radiation injury endpoints - gastrointestinal, hematopoietic, skin damage.
2. Risk secondarily a function of long term effects and career limitation.
3. Acceptable radiation risk may vary with each mission profile.

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Engineering Aspects of Space Medicine

Psychological Factors with Special Reference to Human Performance in Space Flight

I. The Relative Advantages of Men and Machines

A. A brief analysis of the superiority of men or of machines, depending upon the mission, or objectives to be accomplished.

B. The advantages of manned spacecraft.

1. Sensors and computers alone do not tell where to go, and if failures occur, man can take over.

2. Examples from the Mercury flights.

3. Man's ability to reason, use judgment, to make decisions, and to analyze and report.

C. The limitations of the human operator.

1. The impact of environmental factors, such as prolonged weightlessness, radiation, extremes of temperatures, fatigue, and loneliness.

2. The cost and excessive precautions which must be used for human subjects on dangerous missions.

D. Since the decision has been made to send men into space, solutions must be reached to achieve success in a wide range of missions.

1. The engineer should be informed of human capabilities and limitations in the design and operation of all types of equipment in the early stages of each project.

II. Sensori-motor Functions and Skills

A. The role of psychophysical methods in determining design requirements.

1. The relative human sensitivity for various sensory categories.

2. Three kinds of sensory measures, i.e., discrimination, category, and magnitude scales.

3. Threshold studies in relation to long exposures to adverse environments.

4. Combination of multiple variables in the environment.

a. Use of nomograms

B. The application of data from psychophysical measurements of selected sensory functions.

1. Differential light sensitivity in relation to seeing at sea level and at altitude.

2. The combined effects of altitude and selected toxic agents, such as carbon monoxide.

3. Examples from the fields of a) ventilation, temperature, and humidity, and b) noise and vibration.

C. Measurement of skill in sensori-motor performance.

1. Reaction times in the fields of vision and distance travelled in a) low altitude high speed flight, and b) at increasingly higher altitudes and speeds.

2. The effects of accelerative stress on sensori-motor skill and performance.

3. Studies of the effective field of view during visual fixation on displays of various sizes and shapes.

III. The Measurement of Complex Mental Functions and Abilities

A. The importance of understanding higher mental functions involved in the interpretation of data, information processing, and decision making during space flight.

B. The influence of adverse environmental factors and stress on cognitive abilities.

1. The effects of variation in altitude, temperature, and vibration, singly and in combination.

2. Workloads and channel capacity, including vehicle environment in relation to safety and efficiency.

C. Examples of objective measurements in the field of visual perception and interpretation.

1. Eye movement studies in relation to field of view, pattern recognition, and interpretation of the visual scene, including the phenomenon of "looking without seeing."

2. The recognition of patterns in relation to complex stellar and lunar formations.

D. The effects of confinement and isolation on higher mental abilities.

IV. The Implications of the Above Findings for the Design and Operation of High-Performance Aircraft and Space Vehicles.

ENGINEERING ASPECTS OF SPACE MEDICINE

OUTLINE OF

MAN-MACHINE SIMULATION

By

Milton A. Grodsky, Ph.D.

[illegible]mber 2, 1964

I. INTRODUCTION

A. What is man-machine integration? - The development of a system in which the capabilities of both the man and the machine are coupled appropriately so that the maximum performance of the overall system is obtainable.

B. In the development of a man-machine system, one must differentiate between inherent capability and ability to perform in certain environments.

C. Major variables under consideration in man-machine systems.

1. Habitability variables.

2. System or mission variables.

3. Task variables.

D. Importance of man-machine integration to the system.

1. Cost

2. System effectiveness.

3. Mission success.

4. Crew safety.

5. Overall system reliability.

II. SYSTEM INTEGRATION TECHNIQUES

A. Analytical Approach

1. Useful in an ill-defined area.

2. Use of mathematical or quasi-mathematical techniques to determine generalized factors.

3. Useful in early design.

4. As valid as the assumptions made.

B. Laboratory Approach

1. Experimental demonstration of man-machine performance capability.

2. Systematic approach when system problem is sufficiently defined.

3. Artificial in the sense that laboratory performance may differ from flight performance.

C. Simulation Approach

1. Test of concepts and a realistic approach for the collection of data on man-machine problems.

2. Provides a mode of investigation at a similar level to actual flight. Realism of actual flight can be simulated in most areas.

3. Types of simulations.

   a. Part-task.

   b. Integrated mission.

4. Provides training and selection data and can be used as a precursor to actual trainers.

D. Measurement Systems

1. The development of measurement schemes which are unique to man-machine problems.

2. The development of useful conceptual models which are fruitful in the conceptualization of man-machine system problems.

III. SYSTEM INTEGRATION PHASES

A. Conceptual design.

B. Phase I design.

C. Hardware design.

D. Factory test.

E. In-flight evaluation.

F. Personnel training.

The discussion will center on the type of system integration technique suitable for each of the design phases and the particular problems associated with each of these design phases.

IV. EXAMPLES OF PROBLEM AREAS & TECHNIQUES UTILIZED FOR THEIR SOLUTION

A. Pilot Performance Level During Flight

1. Importance of the problem.

   a. Man's role in the system.

   b. Support equipment for man.

   c. System reliability.

   d. Mission success.

2. Measurement of pilot performance. - Use of an integrated mission simulation technique which allows for the collection of a large amount of data on a variety of measures.

3. Results of studies performed.

   a. Capability studies.

   b. Laboratory studies.

   c. Simulation studies.

B. Weightlessness Effects

1. Determination of possible effects and the validity of the available data.

2. Engineering and systems solution to these possible effects.

   a. Artificial gravity.

   b. Exercise.

   c. Drugs.

3. Variables which will determine the engineering approach to be implemented.

   a. Cost and weight.

   b. Physiological protection and performance.

   c. Valid data prior to design.

V. CONCLUDING REMARKS

A. The future of man-machine integration is dependent upon the:

1. Increased complexity of the machine systems.

2. More system automation.

B. Areas such as intelligent machines and automata will eventually become a serious problem area in space flight. Will require inputs from a discipline which can design and put into being the intellectual and decision-making capabilities of man and the strength, endurance, and general tolerance of the machine into a working system.