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ABSTRACT

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UNITED STATES DEPARTMENT OF COMMERCE
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Man, His Job, and the Environment: A Review and Annotated Bibliography of Selected Recent Research on Human Performance

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Preface

Report of A Search for Methodology Appropriate to the Measurement of Physical Effort

As a part of its continuing efforts to upgrade mail service through improving employee effectiveness, morale and working conditions, the Human Factor Group of the Bureau of Research and Engineering, U.S. Post Office Department requested the Technical Analysis Division of the National Bureau of Standards for a study of the measurement of human mental and physical effort. The purpose of this project was to try, under operating Post Office conditions, a number of the approaches to the study of strain and effort that have been developed in recent years, with the intent of assembling a battery of measures which would validly identify the various components of effort. These measurements were to be applicable to any kind of mail-handling task, such as those performed by Manual Distribution Clerks, Multiposition Manually-keyed Machine Distribution Clerks, Manual and Machine Parcel Distribution Clerks, Machine Distribution Sack Sorter Clerks, or Facer-Canceller Operators. The methods developed were to permit comparisons of stress levels incurred in operating apparently comparable machines or keyboards, evaluations of different methods of sorting various types of mail, determinations of the effectiveness of different methods of training, and comparisons of the effectiveness of management or the social environment in one office with that in another.

The project began with a search of appropriate post-1950 literature for the following purposes:

1. To evaluate the results of selected recent research on human effort, especially that concerned with performance changes and physiological and psychological responses to continued physical or mental work.

2. To prepare critical abstracts of the relevant experimental and developmental studies.

3. To provide a background or frame of reference for further research in this area, indicating those methods and results which appeared to lack adequate validation.

4. To determine those measures of effort, strain, tiredness, and performance—and the variables influencing them—which had been demonstrated to be the most valid and reliable and the least redundant; and to recommend them for use in research into environmental, behavioral, and physiological variables which might be identified with the expenditure of physical and mental energy by mail handlers.

Because the focus is on the present state of the art, research conducted before 1950 was not included. References to previous work can be found in the bibliographies listed in part VI B of this report.

No attempt will be made in this report to review or analyze theory or conceptualization of energy and performance costs of work, except as they apply directly to experiment and measurement. We have examined the following forms of literature:

1. Experimental—those studies presenting the results of an empirical investigation into human effort. These reports form the majority of the material considered.

2. Developmental—in which the design or development of experimental methodology, equipment, or a means of measurement was discussed.

3. Review—general articles or book chapters which did not detail original research, but discussed or theorized about research in some specific area of human effort. Most of these articles were not abstracted, but were reviewed and are cited in the Bibliography for this report.

4. Bibliographies—those which have been compiled since 1950 on research into human energy expenditure, performance, fatigue, stress, vigilance, and confinement. Again, these were generally not abstracted, but were used as sources for references and are listed in a section of the Bibliography.

The most important sources of references for this study, aside from the bibliographies mentioned above, were:

1. *Index Medicus*, National Library of Medicine; 1950–1967 literature searched.

2. *Defense Documentation Center*. Current Technical Abstract Bulletins were examined for reports written under Department of Defense contracts, and the DDC computer was queried for post-1949 holdings indexed under the terms "physical fitness," "psychophysiology," "endurance," "fatigue (physiology)," and "stress (physiology)." Nearly 600 citations and abstracts, of which 100–150 were considered pertinent, resulted from this search.

3. *Scientific and Technical Aerospace Reports* (STAR), NASA Scientific and Technical Facility.

4. *Science Information Exchange*, Smithsonian Institution; for current research activities.

5. *Psychological Abstracts*, The American Psychological Association, Vol. **24** (1950) to Vol. **41** (1967).

6. *Sociological Abstracts*, Sociological Abstracts, Inc., Vol. **1** (1953) to Vol. **13** (1965).

7. Various unpublished bibliographies prepared by Ross A. McFarland of the Fatigue Laboratory, Harvard University.

8. *Human Factors Engineering Bibliographic Series*, Volumes **I, II,** and **III** (1940–1965 literature) prepared by the Institute for Psychological Research, Tufts University.

9. *Ergonomics*, Vol. **1** (1957) through Vol. **10** (1967).

10. *Journal of Industrial Engineering*, Vol. **1** (1949) through Vol. **18** (1967).

11. *Administrative Science Quarterly*, Graduate School of Business and Public Administration, Cornell University, Vol. **1** (1956) through Vol. **12** (1967).

12. *Human Biology*, Vol. **22** (1950) through Vol. **39** (1967).

13. *People Consulted:*

Ross A. McFarland, and

Howard Stoudt, both of the Harvard School of Public Health, consulted for their overviews of the history and special problems of research.

James Miller, Office of Naval Research, Psychology Branch, for current research efforts.

Leonard Kibber, Office of Naval Research, Physiology Branch, for current research, and loan of reports.

Suzanne Kronheim, Office of Naval Research, Physiology Branch, for bibliographic information.

Thomas T. Hildebrandt, U. S. Public Health Service, Manpower Resources Program, for information about current research projects undertaken by private industry, and their benefits to the government.

Ralph F. Goldman, U. S. Army Research Institute of Environmental Medicine, for information on the state of the art of physiological research.

Contents

Man, His Job, and the Environment: A Review and Annotated Bibliography of Selected Recent Research on Human Performance

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Recent scientific literature was searched to review procedures currently being used to study human reactions to work and environmental stress. An ecological context is followed, considering task variables, environmental conditions, individual variations in subjects, and physiological, psychophysical, psychological, and sociological responses. The different types of research reviewed included analyses of on-the-job performance, simulations of real-life situations, laboratory experiments with human and nonhuman subjects, and clinical studies. A methodological program is suggested for measuring the expenditure of effort in work situations. In addition to an extensive bibliography, detailed abstracts of 190 research reports are presented.

Key words: Bibliography; effort; environment; fatigue; human performance; human physiology; psychology; psychophysics; stress (physiological); stress (psychological); work.

Introduction

> "Fatigue is to be desired rather than feared. Life without stress is uninteresting and unhealthy. The man is fortunate whose work tires him, gives him a good appetite and promotes a good night's sleep."
>
> David Bruce Dill (1955)

The effects of prolonged or strenuous expenditure of effort are varied, and an individual's response to strain is not simple. Stress resulting from the performance of a particular task may be caused by:

(1) Factors inherent in the task itself. The task may require a large output of physical energy from the performer or it may involve attention for a long period of time with insufficient rest periods. The task may be boring or monotonous, or it may be loaded with trivia. Rules or procedures may be ambiguous, time pressures and the need for success may be imposed, sleep may be deprived, cooperation with fellow workers may be made difficult, and family life may be interferred with.

(2) External, environmental, conditions may interpose themselves to make successful completion of the task difficult or impossible. These may be sudden emergencies such as drastic changes in temperature, atmospheric contamination, glare or blackout of lighting, or loss of oxygen; or they may be long-term exposure to heat, cold, low or high humidity, noise, vibration, high altitude, odors, or aesthetically offensive surroundings.

(3) Defective capacity in the individual. The person required to perform a task may not have been properly or sufficiently trained; he may be "out of shape" or not acclimated. He may be too old or too young or malnourished. He may lack the motivation or personality characteristics necessary for his work.

Strain and fatigue manifest themselves both subjectively and objectively. Psychologists have developed various questionnaires, scales, and check-lists to try to quantify subjective reactions to work and exercise, feelings of monotony or boredom, discomfort, and tiredness. There are also more tangible psychological and psychophysical factors which can be measured. Operant behavior, coordination and steadiness tests, problem-solving, and reactions and reflexes can be used as indices of more intangible factors of perception, cognition, and capacity for performance. Biochemical changes in the body content of such things as lactic acid, blood sugar, oxygen and carbon dioxide also result from prolonged activity. The consumption and distribution of food energy and the liberation of waste products resulting from nerve or muscular response can be measured indirectly by respiration and metabolic measures, heart rate, blood pressure, perspiration, and body temperature changes.

Task performance can be evaluated directly through the number of errors made and by measuring the rate and consistency of output. Strain gages can record the amount of effort required for a task, and tests of strength and endurance can estimate an individual's capacity. Measuring output over a period of time will show whether performance decrement or enhancement occurs.

Certain amounts of strain, tiredness, and performance change are unavoidable, and by investigating the interactions between the task, the individual, and the environment, they can be kept within ranges acceptable to both the job and the worker.

The following chapters present a review of the 190 abstracts included in section VII. References to the abstracts are given in the text by author and date of publication (for example: Baker [1958]). DDC numbers (for example: DDC AD #123,456) appearing in the citations for some of the items abstracted or listed in the bibliographies, indicate that the particular document is in the Defense Documentation Center collection and may be ordered from DDC, Cameron Station, Alexandria, Va. 22314, or from the Clearinghouse for Federal Scientific and Technical Information, Springfield, Va. 22151.

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II. Types of Research into Physical Effort

A. "On-the-Job" Performance Studies

1. Industrial Studies

Brouha [1953 and 1960 a-f] discusses industrial fatigue in great detail, presenting many concrete examples of research results. His emphasis is on physiological responses to stresses such as those encountered in iron foundries, steel mills, and chemical plants. He summarizes many studies of materials handling, heat stress, and respiratory contamination, in which heart rate and heart rate recovery were determined to be the most valid and effective response indicators. Christensen [1953] also describes a physiological study of an iron works, in which pulse rate, oxygen consumption, metabolic rate, skin and rectal temperatures, and fluid discharge were measured.

Shepherd and Walker [1957] conducted a sociological analysis of absences in an engineering firm and two iron and steel plants. From personnel records were taken employee age, length of service, wage rate, job title, and one-year absence record. Because of the large number of job types considered, working conditions—heaviness of work, heat exposure, presence of dust or fumes, and task continuity—were evaluated subjectively by foremen and managers rather than being objectively determined.

A Kerr "tear ballot" was used by Griffith et al. [1950] to measure subjective feelings of tiredness during the working day by 75 foremen and 232 manual workers in a factory and by 48 male and 24 female office workers.

2. "White Collar" Studies

Laporte [1966] compared two forms of rest pauses, using 80 women in the Brussels Post-Cheque Office. Half of the women took a standard, "passive" break in their work, while the other half performed gymnastic exercises. Instrument reading was studied by Vincent [1965] in a comparison of two azimuth alinement procedures for Minuteman missile theodolites. Measures used were variance of instrument readings, the time required to complete 20 readings under each configuration, and operator complaints, which were vociferous. Psychological and sociological conditions at a SAGE Direction Center were assessed by Green [1960] in a questionnaire given to 194 workers in 8 different operator-teams.

Kikolov [1960] reports a study of technicians at subway and TV studio control boards, using measurements of reflexes, blood sugar, and blood pressure. Critical Fusion Frequency was the major fatigue criterion used in three studies of female telephone operators [Grandjean 1959, Grandjean and Juan 1960, and Fischer et al., 1961]. Grandjean also used reaction time, speed of addition of figures, tremor, and the Bourdon vigilance test in his study of 13 to 15 telephone operators and 14 "bureau employees." Manual skill and optical reaction time were also measured by Grandjean and Juan [1960] for 25 night-shift telephone operators.

Lunderwold [1957] emphasized muscle action electrical potentials, in addition to pulse rate, breathing rate, and sweat gland activity, in an investigation of typing and tapping a typewriter key under conditions of varied room temperature, noise level, and illumination intensity.

3. Combat

Studies of U. S. infantrymen in front-line combat in Korea are reported by Pace et al., (n.d.) and by Davis and Taylor [1954]. Psychological and physiological assessments compared pre- and post-combat states and also the effects of short, intensive, attacking combat versus longer, less intensive, defensive action. Domanski [1953] evaluated the eosinophil responses of 21 F–85 fighter pilots on combat patrols in Korea: and Plattner [1967] describes Roman's studies of Navy carrier pilots in combat over Vietnam, in which heart and respiration rates, acceleration forces, and communications were monitored. Austin et al. [1967], also studied Navy carrier pilots in Vietnam, measuring ECG and respiration and acceleration rates in flight on 32 pilots. Pre- and post-flight collections were taken of blood and urine, and carrier landing performance was analyzed from radar trackings.

4. Flying

Four, three-man antisubmarine warfare helicopter crews were studied by Davenport [1955] on noncombat patrols. Movements of the helicopter were recorded, as were the subjects' post-flight steadiness, speed and coordination, tapping rate, CFF, and hearing. Subjects were interviewed and given a subjective questionnaire. Aircraft movements were also recorded by Jackson [1956] on 15-hr night reconnaissance flights over water by 10 pilots. Accuracy of altitude and heading were examined for consistency. In a study by H. P. R. Smith [1961], observers recorded pilots' sleeping hours, meals, smoking, judged emotional state, errors, cockpit atmosphere, meterological conditions, air and ground speeds, communications, and navigation.

Flying Personnel Research Committee (n.d.) observers kept a running log on four BOAC Boeing 707 jet captains for four transatlantic flights each. Heart rate was recorded during the flights, and urine was collected on flight and control days. Subjective-fatigue check-lists were also administered to the pilots, and respiratory end-tidal samples were taken on the taxi-strip at the end of some flights. An extensive series of subjective and physiological measures were made by Ruff et al. [1966] on 75 crewmen of 25 transatlantic flights by a German airline. Measures included pulse rate, blood pressure, ECG, oral temperature, eosinophil count, hematocrit value, coordination and optical reaction time.

5. Motor Vehicle Driving

A 1200-mile round trip on 4-lane highways was made in a sedan with two alternating drivers [Platt, 1964]. A Drivometer in the car's glove compartment read out time, mileage, the number of steering reversals, accelerator reversals, speed changes and brake applications. I. D. Brown [1962] describes a series of attempts by the British Applied Psychology Unit to develop objective measures of driving performance in real-life situations. The researchers tried using the pattern of component movements, position of the car on the road, and consistency in reproducing various actions; but rejected them as being unintelligible, insensitive, or lacking in quantification. A method which was found to meet these criteria and, in addition, measure the reserve capacity of the driver, is to give him a subsidiary mental task to perform while driving. Herbert [1963] developed and administered a battery of precision vehicle-handling tests, which were used [Herbert and Jaynes 1963] in a fatigue experiment to study the effects of 0 to 9 hrs of truck driving upon driving performance precision.

B. Simulation of Real-Life Situations

Goldman [1965] attempted to simulate the stresses of infantry combat by using tactical training problems. Metabolic rate, ventilation volume, and oxygen content of expired air were measured for 24 infantrymen. Unfortunately, the degree of fatigue and fear present in true combat was probably lacking in the simulation. Energy costs and metabolic requirements were undoubtedly affected by the respiration gasometer and clothing worn by the subjects.

C. Laboratory Experiments With Humans and Non-Humans

1. Non-Human Subjects

Blake and Proctor [1965], in the development of fatigue-producing performance tasks, used a simulated partial space-flight as a test situation for 160 orbits with five monkeys, 50 orbits with seven humans, and training data for three chimpanzees. Accuracy and rate of output were analyzed for symbol-matching learning tasks, some with interfering information or reversal required, and some with rewards or electric shock. Byck and Hearst [1962] also used an endurance situation in which rhesus monkeys were required for 120 hr to press a lever to avoid receiving an electric shock. The monkeys appeared to be able to adjust to the fatiguing situation, as avoidance of the shock increased with time. Continued physical exercise—climbing and lifting a bucket at times containing a 5-kg weight—was studied in rhesus monkeys by Miller and Mason [1964]. Blood was collected from an indwelling cannula in the monkey's right jugular vein and urine was collected automatically by a drain in the cage floor. Analysis of these fluids was performed for the level of 17-hydroxycorticosteroid secretion of the adrenals.

The effects of magnesium and potassium salts of aspartic acid (spartase) on swimming endurance of dogs and rats were evaluated by Matoush et al., [1963]. The animals were required to swim to exhaustion, some while carrying weights, in water at a temperature of either 17° C. or 25° C. Rats were used by Todd and Allen [1960] in a series of experiments into the relations between carbohydrate maintenance of glycogen and cold stress, cold-and-fatigue, insulin stress, and swimming endurance. Factors affecting the numbers of circulating eosinophils in the blood were studied in mice by Visscher and Halberg [1955].

2. Human Subjects

Exercise bicycles, familiar to health club enthusiasts, are found in human performance laboratories in the form of bicycle ergometers which the subject pedals against a particular resistance and at a set speed. Nagle et al. [1966] used a bicycle ergometer as a standardized exercise in a study of the comparative accuracy of two methods of blood pressure measuring. Ekey and Hall [1961] used both a bicycle and vertical torsion bar ergometer, and measured heart rate, GSR, blood pressure, air temperature, relative humidity, and relative physical fitness. Brouha and Maxfield [1962] studied the effects of environmental temperature on oxygen consumption and heart rate during intermittent work on the bicycle. Maximal exertion on the bicycle was investigated by Astrand and Saltin [1961], using measures of oxygen uptake, heart rate, pulmonary ventilation, and the lactic acid concentration in the blood.

Balke [1954a] used a treadmill test in his investigation of the effects of strenuous physical exercise upon respiratory gas exchange and cardiovascular functions. A treadmill with a slowly tilting bed was used by Domanski et al. [1951], to measure blood eosinophil response to a physical exercise situation lacking the interference of psychological stress. The effects of magnesium and potassium salts of aspartic acid on work capacity and endurance were investigated by Consolazio et al. [1963], and by Nagle et al., [1963]. Physiological costs of wearing an armored vest and carrying a back-pack have also been studied on treadmills [Daniels et al., 1953; Winsmann et al. 1953]. Direct comparisons between treadmill studies are difficult, as different investigators have used different walking speeds and angles of slope—3.2 mph and unspecified slope changes [Brouha and Maxfield, 1962], 3.4 mph with slope increasing each minute ½ percent of the belt travel per minute [Balke, 1954a,] 3.5 mph and level bed [Daniels et al., 1953; Sharkey et at., 1966; and Winsmann et al. 1953], 3.5 mph with slope increase of 1 percent per minute [Domanski et al. 1951], 3.5 mph at grades of 0, 4, 6, 8, 10, and 12 percent [Sharkey et al 1966], 4.0 mph at 3.5 percent grade [Consolazio et al. 1963], and self-paced [Evans, 1961, 1962; and Holmgren and Harker, 1966].

Arm and wrist strengths and endurance were studied by Hunsicker [1957] and Watt and Innes [1963] in simulated aircraft cockpit situations. Isometric handles and hand dynamometers have been used to study the effect of an analgesic drug on muscular work decrement [Caldwell and Evans 1962], the effects of aspartic acid salts on fatigue [Evans and Caldwell 1962], and the effects of ingesting orange juice on fatigue resistance [Mack and Dixon, 1955]. Auxter [1966] compared the abilities of mentally retarded and normal children to withstand the onset of muscular fatigue as measured by hand grip strength on a dynamometer. Similarly, Schwab and Brazier [1958] studied fatigue and muscular performance impairment in patients with neurological and psychiatric disorders, by using hand dynamometers, step tests, ergograms, and a hanging bar test. Schwab earlier [1953] analyzed the effect of motivation levels on performance of such strength and endurance tests as the hand dynamometer, spring and weight recording ergographs, and hanging bar tests.

Step tests have been used as a measure of physical fitness and endurance, although they normally require the use of only the lower body muscles. The standard test, the Harvard Step Test (HST), requires the subject to step up and down 30 times a minute on a 20-in. step. Endurance can be measured by the length of time the subject is able to maintain the pace, and fitness by the rate at which the pulse rate returns to normal after exercise for a set period. The HST was used by Kreider et al. [1961], as a measure of fitness of subjects working on the Greenland icecap, and by Mack and Dixon [1955], as one measure in their evaluation of the use of orange juice as a fatigue-resisting agent. Since Mack and Dixon studied 10 to 19 year old children as well as adults, they used, in addition to the 20-in step, a 17-in one for the shorter subjects. Patterson et al. [1964], modified the HST by adding horizonal bars above the rear edge of the step. This permitted subjects to use their arms as an aid in ascending and descending the step, thus using a greater percentage of the total body muscle mass. As a control for individual weight differences, one series of subjects exercised while wearing a back pack loaded to one third of their body weight.

DeVries and Klafs [1965] used a 20-in bench stepping test at a cadence of 36 steps per minute. As some men were able to exercise for over 6 min and appeared to stop for reasons other than physical fatigue, male subjects were asked to hold 15-lb dumbells at arms length behind them. Schwab and Brazier used a step test consisting of two 12-in steps. Strydom and Wyndham required subjects to step on and off a step 12 times a minute for 4 hr in a hot-humid atmosphere. The height of the step was adjusted according to the subject's body weight, so that all subjects would undergo the same work load, of about 1,560 ft-lb per minute.

D. Clinical Approaches and a Case History

Spaulding [1964] discusses the methods and results of a survey of 4,000 consecutive medical out-patients at a Toronto clinic. He found that, while psychiatric disorders appeared to be the causes of half of the cases in which fatigue was the major complaint, almost all the major systems of the body had representatives in the list of physical causes of fatigue. Spaulding stressed the point that an orderly approach to the symptom should include in-depth investigation of the character, duration, circumstances of onset, time of daily maximal intensity, precipitating and relieving factors, and accompanying factors.

Coates [1964] and Wilbur [1953] discuss diagnosis, evaluation, and management of chronic fatigue and tiredness. Walters [1964] found that over 94 percent of a series of his patients complained of fatigue. His reported treatment consists of dietary prescriptions and supplements. Tebrock et al. [1959], tried out a preparation of three analeptic (stimulant) drugs on a group of patients in a study seriously lacking in controls and quantifiable measures. Better controlled studies have been done by Shaw et al. [1962], and by Taylor [1961] into the effects of the potassium and magnesium salts of aspartic acid upon patients complaining of general, persistent tiredness. Whittenburg and Weiss [1952] conducted a literature search into the feasibility of using some measure of olfactory sensitivity as an indicator of systemic fatigue.

David Bruce Dill [1961] presents an excellent, albeit brief, discussion of his cardiovascular responses to exhausting exercise on treadmills and bicycle ergometers over a period of some 34 years.

E. Design and Development of Methodology and Equipment

Evans [1961 and 1962] developed a titration schedule to enable continuous monitoring of performance capability changes in subjects walking a treadmill. The subject holds a switch which he can activate to increase or decrease the belt speed by two feet per minute per second, and he continually monitors the treadmill speed to allow himself to walk at a fast but comfortable rate for as long as possible. Holmgren and Harker [1966] modified the Evans treadmill to track automatically the subject's pace and adjust the belt speed to the subject. In this manner, a "comfortable-but-determined" pace was established for each of 19 soldiers.

As treadmills are often used to simulate normal walking or running conditions, it is useful to know how similar the two situations actually are. Daniels et al. [1953] compared metabolic costs of a group of soldiers walking at 3.5 mph on a treadmill and outdoors on a cinder track and on an asphalt pavement. Mean Metabolic rates were 5 to 10 percent greater for walking under normal conditions than while walking on the treadmill. The authors speculate that the treadmill changes the body mechanics of walking.

Rasch and Wilson [1964] undertook a series of tests to correlate four physical fitness tests: Harvard Step Test, Harvard Treadmill Test, Balke Treadmill Test, and Marine Corps 3-mile run in field gear. Correlations between most of the tests were very low, indicating that they measured different aspects of physical fitness. The only high correlation obtained was that between the Balke Treadmill Test and the 3-mile run ($r = -0.76$, significant beyond the 0.01 level). The correlation is negative because, while higher scores are desirable in the treadmill test, lower times are better for the 3-mile run.

Sharkey et al. [1966] tested the use of pulse and ventilation rates of subjects walking on a treadmill at various slopes as predictors of energy costs (in oxygen consumption) of other exercises. The authors concluded that (a) ventilation rate was more accurate than pulse rate in predicting oxygen intake, and (b) greater precision resulted when the task was similar and required the use of the same muscle groups as those used for the task from which the prediction equation was developed.

Greene and Morris [1959] and Barany and Greene [1961] describe the construction of a force platform for recording forces exerted by a subject engaged in light to moderate work. The platform top rests on three sensing elements which record forces exerted in 3 dimensions, and the device is sensitive enough to detect the heart beat of someone standing on it. Workers can be tested for their ability to establish a rhythmic movement pattern with a minimum of false or wasted motions, and an ideal pattern can be established as a model for improving performance.

Simons et al. [1965] describe technical details of a data-acquisition and radio telemetry system for collecting, transmitting, and recording performance and six biomedical responses of subjects. Electrodes and sensors taped to the subject pick up EEG, ECG, respiration rate, skin temperature, basal skin resistance, and GSR. Battery packs, preamplifiers, and transmitters are fitted into a vest worn by the subject, and the physiological data are radioed to a remote receiving, monitoring, and recording station. Plattner [1967] discusses somewhat similar equipment which has been used to monitor ECG, heart rate, voice, and respiration rate of pilots in combat flights over Vietnam and during carrier launchings and landings. A vectocardiogram, with electrodes contained in a vest, is being developed to measure the three-dimensional spread of electrical excitation over the heart muscle. Heart rate and rhythm of free-fall parachutists have also been measures [Schane and Slinde, 1967] by ECG and recorded by a tape recorder which the subjects wore. Muller and Reeh [1955] describe a device containing a photoelectric cell and lamp which are fastened to the earlobe to measure pulse frequency from density changes as blood pulses through the earlobe.

Hess and Polt [1964] discuss their method of photographically recording changes in the diameter of the pupil of the eye during mental computation. The procedure requires that the subject fixate his gaze on a particular spot, to reduce movements which could compromise accurate measuring of the filmed image of the pupil.

Perspiration loss from the body has most often been calculated from a comparison of pre- and post-exercise body weights. In addition, some devices have been developed to measure sweat evaporation directly from small areas of the skin. Randall et al. [1953] report tests on the efficiency and reliability of the desiccating capsule technique. A small aluminum capsule containing an activated alumina desiccant absorbs perspiration evaporated from an 8.54 cm^2 skin area. This method enables comparison to be made of perspiration rates from differnt parts of the body. A thermal conductivity cell, report Adams et al. [1963], can measure moment-to-moment changes in perspiration rate from local areas on the body. The system uses a stream of air which flows over the surface of the skin and absorbs water vapor lost by the skin. Variations in the humidity of the air stream cause air density changes which can be measured by the thermal conductivity cell. This allows measurement of the instantaneous perspiration rate, changes in water vapor production, and total water produced over a given time.

Whittenburg and Weiss [1952] suggest that some measure of changes in olfactory sensitivity be used as an indicator of systemic fatigue.

III. Independent Variables Associated With Effort

A. Task Variables

1. Introduction

There are three major factors which are involved in any consideration of task performance: the task itself, the individual performing the task, and the environment in which the task is performed. The nature and demands of the task, the characteristics inherent in the individual which affect his ability to carry out the task, and the limiting and facilitating features of the environment must each be evaluated as parts of an interrelated system, every part of which affects every other part. These three factors are discussed in this section (III) of this report, in the above order.

Mohler [1965, referenced in section VIA] lists the following task demands which may be detrimental to satisfactory performance:

"Protracted immobility required of the individual
Excessive psychosensory task demands
'Time-pressure' stresses
Excessive task loading with trivia
Frequent emergencies or false alarms
Task challenge or interest and compensation

Ambiguous rules or procedures
Interrupted family life
Time-zone changes required."

The "heaviness" of work and the number of muscle groups involved are related to the length of time an individual may be able to continue at a task or remain on the job. Patterson et al. [1964] found that their subjects could endure a step test for a significantly longer time if a series of horizontal bars was installed above the step so that the subjects could use their arm and shoulder muscles in addition to their legs. Shepherd and Walker [1957] discovered that lost-time rates and frequency of absence from work by manual laborers varied directly with the physical heaviness of their jobs. While 30 percent of the men doing heavy work had more than 6 absences per year, only 13 percent of the workers involved with light work had over 6 absences. Conversely, 64 percent of the men performing light tasks had 0 to 3 absences per year, while only 47 percent of the workers on heavy work had as few absences.

2. Work-Rest Ratio

Shepherd and Walker also found that, for jobs which were continuous or included some (as contrasted with many) pauses in the activity, absence rates decreased as the work also became physically lighter. For workers performing physically strenuous tasks, absence decreased as rest pauses increased. Brouha [1960e] relates that when a standardized system of work and rest periods was implemented by one company for men working with very hot furnaces, their body temperature response and heart-rate recovery from work were definitely improved. During the second half of the eight-hour shift the lengths of both work periods and rest breaks were shortened to counteract the buildup of strain and fatigue. In addition to the improved physiological responses, absenteeism and employee turnover were markedly reduced, and production did not fall off during the warm summer months as it had before the new schedule was introduced.

Adams and Chiles [1960] compared human performance in four work-rest schedules over a 96-hr period: 2 hr on duty and 2 hr off, 4 on and 4 off, 6 on and 6 off, and 8 on and 8 off. The subjects performed monitoring, computational, and discrimination tasks and were given an attitude questionnaire at the end of the experiment. Within the 8-hr group, performance was best on the more active tasks, while a reasonable level of motivation was maintained for all tasks in the 2- and 4-hr groups. Although the data from the experimenter's logbook and the subjective questionnaires did not significantly differentiate the groups, there were indications that the 2- and 4-hr groups appeared to have adjusted more favorably to their schedules than did the 6- and 8-hr groups. The same battery of psychomotor tasks was used later [Adams and Chiles, 1961] in a 15-day test of a 4-hr on duty, 2-hr off cycle. Performance on the arithmetic computation, [illegible]ability monitoring, and auditory vigilance tasks reflected a trend toward decrement throughout the 15 days, while performance on a pattern-discrimination task improved. A significant diurnal variation in performance was observed for all tasks, and this variation slowly decreased in amplitude. Heart rate and respiration rate decreased during the period, and skin resistance increased.

Half of a group of students performing an hour-long inspection task were told they would be given a rest period in the middle (Colquhon, 1959]. Scores for the first half-hour were identical for both groups. During the second half-hour, however, performance declined for the no-rest group, while performance by the group given a 5-min break was maintained at its initial level throughout the hour.

Payne and Hauty [1957] compared the performance of groups of subjects working for 4 hr on a multidimensional pursuit task with 1-min work periods separated by rests of 15, 90, or 240 s. The results indicated that the rate of performance decrement varied inversely with the length of the intertrial rest interval.

3. Content of the Rest Period

Ricci, et al [1965] compared two traditional methods of recovery following strenuous running exercise. The physiological parameters that were measured indicated that standing still was as effective a form of recovery as was walking. The subjects expressed a preference for walking, however, stating that their legs became "tired" and "tight" while standing after a brief run.

Large groups of women working in the Brussels Post-Cheque Office took a passive rest pause or performed gymnastic exercises for 10 min in the middle of the afternoon while on the job. After the break, the women who exercised were found to perform very significantly better than the controls at Wechsler's digit-symbol test and the fusion flicker frequency test ($p < 0.001$), and also scored higher on a hand dynamometer and on Piéron's dynamic tremor test.

4. Task Difficulty

Balke [1954a] found pulse rate to be directly related to increased work load when subjects worked at various percentages of their optimal work capacity on the treadmill. Systolic blood pressure following work varied inversely with the work level, while diastolic pressure remained practically unchanged. Shepherd and Walker [1957] reported that manual laborers who had heavier jobs also had more absences and greater lost time than workers on easier jobs. When their work required continuous effort or had some pauses in it, the workers' absence rates decreased as the work also became lighter physically.

Although technicians could perform theodolite settings as fast and as accurately when working in a cramped position as when in a more comfortable one, their complaints about the cramped position were vociferous [Vincent, 1965]. Very high correlations were found by Young [1956] between heart rate and the pace at which students pumped a small hydraulic hand pump. Heart rate recovery curves after work at different paces sometimes crossed, however. Glassner and Peters [1959] found the level of physiologic response to be inversely related to task difficulty level when subjects performed mental tasks from the U.S. Army General Classification Test.

B. Environmental Factors

1. Temperature, Humidity, and Movement of the Atmosphere

It is well known that environmental temperature and humidity affect human physiology and performance. Specification of these two factors alone, however, does not provide sufficient description of the thermal conditions present, for the rate of air movement and the radiation of surrounding objects also affect the individual. For example, if the rate of heat absorprtion by surrounding objects is low enough, one may feel comfortable in indoor clothing with the air temperature as low as 40 or 50° F. Bedford [1953] discusses these factors and various scales of warmth which allow for them. In addition to measuring the general atmospheric conditions of the study environment, the experimenter should also consider the micro-environment—the very thin envelope of air next to the individual's skin, where the interaction between individual and environment actually occurs. Clothing, by restricting the movement of air to and from the surface of the skin, inhibits body heat dissipation. This may be advantageous in a cold environment, but can cause an incapacitating heat buildup under certain warm conditions, especially if air-impermeable protective clothing is worn.

Brouha [1960e] reports an investigation of work (treadmill walking) alternating between warm and cool workrooms with less than 30 s between conditions. Whether the subject worked first under the cool condition and then in the warm room or vice versa, had no effect on the maximum heart rate attained during work. The cardiac debt, however, was 39 percent smaller when the work cycle progressed from warm to cool conditions, and the speed at which the heart rate returned to normal was faster, indicating that the subject was able to pay part of the heat debt accumulated under warm conditions while he continued to work in the cooler environment. As environmental temperature and humidity increased from normal to warm-dry and to warm-humid conditions, so also did physiological strain (as measured by heart and respiration rates, oxygen consumption, and carbon dioxide production) of men and women pedaling a bicycle ergometer [Brouha, 1960c]. Carlson [1961] compared performance on a vigilance task in environmental temperatures of 20, 25, 40, and 50° C. Blood flow, rectal temperature, water loss, and respiration rates all increased slightly with temperature increase, and performance was adversely affected by temperature increase when high levels of output were required.

Baker [1958a] compared physiological responses of Negro and White soldiers to hot-humid and hot-dry atmospheric conditions. As measured by rectal temperature, sweat production, sweat evaporation, and pulse rate, Negroes showed a better tolerance than Whites to the hot-humid condition while clothed and walking, and suntanned Whites had the higher tolerance under hot-dry nude-exposed-to-the-sun conditions. In a comparison of the performance of subjects from different ethnic groups on an endurance step test in hot-humid conditions, Strydom and Wyndham [1963] found little differences between groups who have been similarly active in the same environmental conditions. There were, however, large differences in endurance and in pulse and perspiration rates between acclimatized and nonacclimatized groups. Brouha and Maxfield [1962] observed two subjects pedaling bicycle ergometers for eight or ten successive five-minute periods with intervening rest periods just long enough to permit oxygen consumption rates to return to pre-exercise levels. Two atmospheric conditions were tested —comfortable (dry bulb temperature 72° F. and 50 percent relative humidity) and uncomfortably warm (DB 91° F., RH 97%)—and oxygen consumption curves behaved similarly in the two environments. Heart rates, however, although attaining relatively steady states in comfortable surroundings, increased during each work period and ended at progressively higher levels with each cycle in the warm environment.

Performance of a simulated small-parts inspection task was evaluated by Chiles [1958] under five atmospheric conditions— 85° F. dry bulb and 75° F. wet bulb, 90°/80°, 110°/90°, 120°/90°, and 120°/105°. No significant differences were found in performance. Ward et al. [1965] used the critical fusion frequency response as an indicator of mental performance capability, and found that following a subject's exposure to a temperature of 82° F. and a relative humidity of 70 percent for 3 hr, the flicker fusion point was lower than before exposure.

Two studies [Klein, 1961; Lundervold, 1957] have demonstrated an increase in the electrical action potentials of muscles during and after exposure to moderate or severe cold. When subjects worked in a room at a temperature of 59° F., their muscles contracted more vigorously and they used more muscle tissue to tap a typewriter key than when working at 68° F.

Matoush et al. [1963] observed that rats could not swim nearly as long in 17° C. water as they could in water at 25° C. Doses of Spartase failed to mitigate the effects of the cold water.

2. Altitude or Oxygen Pressure

Physical fitness, load-transport performance, and the volume and mass of inspired air were evaluated by Kreider et al. [1961], for 19 soldiers who spent approximately two months on the Greenland ice cap at an altitude of 7,000 ft. The volume of air inspired (corrected to STPD—standard temperature and pressure, dry) of the subjects when performing a mild step test at 7,000 ft was 8 percent greater than the value recorded 19 days after return to near sea level. The value remained high, however, for at least 12 days after the return.

Hansen et al. [1967] describe two studies of acute mountain sickness. A group of seven soldiers who had been stationed at an altitude of 5,200 ft reported no significant change in symptoms (as measured by a 39-item subjective checklist) when they were moved to an altitude of 11,400 ft. For six subjects who were transported rapidly from sea level to 11,400 ft, significant changes in neuromuscular and cardiopulmonary symptoms occurred during the first three days at altitude, and all symptom scores returned to baseline values within one week. A lessened desire to work was equivocally seen in both groups while at altitude. In the second study, subjects who were transported rapidly from sea level to 14,100 ft displayed greater changes in symptoms upon arrival than did subjects who spent one-week stops at 5,200 and 11,400 ft enroute. By the second week at 14,100 ft, only the cardiopulmonary subjective scores were still changed from sea level values ($p < 0.05$ level in both groups of subjects).

In the study of the men transported from sea level to 14,100 ft, blood pressure, heart rate, and cardiac output were measured while the subjects exercised on a bicycle ergometer. These measures were recorded during the first four days the subjects were at altitude and again between the fifteenth and eighteenth days—a length of time insufficient for the full effects of physiological acclimatization to be realized. Heart rate, cardiac output, stroke volume of the heart, and both systolic and diastolic blood pressure all increased significantly when the subjects first arrived at altitude; but all measures except heart rate returned to or near to sea-level values by the third week at 14,100 ft. Resting heart rate remained 18 percent higher than the sea-level value for the entire two to three weeks spent at altitude. Heart rates recorded during mild and moderate exercise were higher at altitude than they had been at sea level and decreased slightly during the stay at altitude, while the average heart rate during maximal exercise at 14,100 feet remained lower than the initial sea-level rate throughout the stay at altitude.

3. Noise and Music

Bitterman and Soloway [1946] tested 10 subjects on the Minnesota Vocational Test for Clerical Workers for four, 15-min periods. During two of the periods, a recorded voice reciting numbers was played at 60 dB. Output, accuracy of test scores, and frequency of eye blink rate did not appear to differ significantly between two conditions—with or without the background voice. Mean heart rate, however, was significantly higher during the work performed under distraction than that done in silence ($p < 0.01$; 88.0 beats per minute during the distracting noise versus 85.9 bpm in silence).

Electromyographic recordings made by Lundervold [1957] of muscles used in typing indicate that, when background noise of up to 90 dB is introduced, muscles are contracted more vigorously than normal and the number of muscles participating is increased.

Wokoun [1963] compared the vigilance performance of subjects on a discrimination optical stimulus-response test while listening to a Muzak tape with their performance while a small office fan was running. The performance of the subjects who performed while hearing the noise did not change significantly during an hour's work. Subjects who heard the background music, however, responded significantly faster to the occasional stimulus during the latter two-thirds of the hour than during the first 20 min.

4. Illumination

Ryan [1953] describes briefly an experiment in which 60 subjects performed a visual inspection task for three 10-min periods. Glare produced by a bare 100W light bulb positioned 10° above the working material and about 30 in from the eyes was present during the middle work period for 20 of the subjects and during the last period for another 20. Electromyographic recordings were made of muscles not directly used in the task. Not all subjects demonstrated an increase in muscle action potential when the glare was present. The only significant effects of glare appeared when glare was present during the middle 10-min period. Although the subjects who worked under glare in the third period produced their highest MAP at that time, the control group also produced its highest MAP during the third period, and there was very little difference between these two groups.

Ryan [1953] also conducted a series of three experiments into the relationships between various levels of illumination intensity and MAP. No significant differences in MAP level were found whether the subjects performed the vigilance task under 5 fc or 18; at 5, 15, or 50 fc; and when 15 fc was compared with 5 and 2.5.

Travis et al. [1951] varied the level of illumination during a reading task with a variable-speed motor-controlled shutter beneath a bank of overhead fluorescent lamps. The control was set to change the illumination level while the subjects were reading from 40 fc to 0.2 fc at a linear rate in approximately 11 min, a rate slower than the dark adaptation mechanism of the eye. Electromyographic recordings were made from two surface electrodes placed over the muscles above the subject's eyebrows. Apparently only a very few subjects were tested, and the results were variable and were not analyzed for the group as a whole.

Ryan et al. [1953] investigated the effects of prolonged visual work and glare upon the flicker fusion frequency. A series of tests were made with small numbers of subjects reading for $3\frac{1}{2}$-hr periods in an ambient brightness of 2, 11, or 50 fL. Glare caused by a 25-W bulb behind a ground glass placed slightly above the line of vision was introduced in one portion of the experiment. These different illumination conditions did not differentially affect the flicker fusion response. In a somewhat similar study, Collins and Pruen

[1962] had subjects performing settings on a vernier gage for 2 hr in illumination of one or 30 lm per square foot. Although the time to perceive Landolt rings increased significantly over the 2 hr for each condition, there was no significant difference in perception times between the two different levels of illumination.

Similarly, Brozek and Simonson [1952] studied performance of a 2-hr visual inspection task under three levels of illumination—5, 100, and 300 fc. Significant differences were found for performance, performance decrement, average eye blink rate, and the change in recognition time for threshold-size dots after work at the different brightnesses. There was, however, no significant relation between illumination level and change in fusion flicker frequency, rate of eye movements, or subjective discomfort score. Performance and performance decrement appeared in the study to be the most sensitive indices of adequacy of the level of illumination.

5. Chemical, Biological, or Radiological Contamination

Zapp [1960] discusses physiologic responses of men and animals to the chemical environment. In one study, two groups of manual laborers, one group exposed to nitroglycerine and the other not, completed a work cycle with the same average heart rate as measured within 1 min of sitting down. For successive readings during a 15-min recovery period, the unexposed group showed a typical heart-rate recovery, but the men who had been exposed to nitroglycerine maintained a comparatively fast rate for the entire period. In another study, dogs and rats were exposed to chlorotrifluoroethylene at levels which produced no outward clinical evidences of toxicity. Changes in blood pressure and hematological changes, however, were found in the dogs, and severe tubular necrosis was revealed in the rats upon sacrifice.

In Shepherd and Walker's [1957] analysis of absence and the physical conditions of work, the managers and foremen who evaluated the jobs discussed were asked to state whether fumes were present or not, and whether the particular working conditions were dusty, moderately dusty, or free from dust. Dusty conditions included exposure to particles of iron ore in the ore preparation and sinter plants and dust from coal and coke in the coke ovens. Examination of absence records did not suggest that these conditions had any general effect on absence behavior—the absence rate of men under 45 years old who were exposed to both dust and fumes was 2.92 shifts lost and for those who were exposed to neither the rate was 3.45; for the older men the rates were 4.57 and 4.14, respectively.

DeVries and Klafs [1965] tested the hypothesis that breathing negatively ionized air would result in improved physical performance. Forty-five male and female college students exercised to exhaustion on a 20" step test after 15 min of exposure to positively or negatively ionized atmosphere, normal room atmosphere, and a placebo situation in which ion machines were present but not operating. No significant relations between treatment and endurance were found. A majority of the subjects did, however, when asked which treatment room made them feel best, indicate the room which had the negative ionization; and a number reported headaches and feelings of dullness in the positively ionized room.

A series of behavioral experiments was conducted by Chiles et al. [1960], under five atmospheric conditions: medium positive, high positive, medium negative, and high negative ionization; and no ions present. There appeared to be no significant relationships between ionization and performance on any of the tests—the individually performed Mackworth Three-Clock Test, a group inspection task, and a group discussion, cooperation, and intragroup attitude evaluation task.

6. Gravitational Force

Walk and Sasaki [1965] used a rowing task to compare energy expenditures under these conditions: laboratory, level 1G flight in an airplane, 2G – 1G – 2G aircraft banking maneuvers, and 2G – OG – 2G aircraft parabolic flight. Because the various gravity conditions could be maintained for only a very short time in flight, the rowing task was performed for only 12 s at a time, but was repeated until a 2-min sample of the subject's expired air was collected under each gravity condition. The volumes of expired air, oxygen, and carbon dioxide were not significantly different between conditions.

7. Clothing

The clothing which an individual wears modifies, at times drastically, the relationship between his body and the external environment. Clothing may act to screen heat or cold, radiation, moisture, chemical and physical contaminants. When a person is working in the heat, clothing which protects the skin from heat radiation and sunburn, may at the same time inhibit the effective evaporation of perspiration from the body surface, and thus increase the heat stress. Brouha (1960e) recommends that workers exposed to severe heat stress such as encountered in steel mills wear air-permeable ventilated clothing to increase the flow of air at the body surface and facilitate perspiration evaporation.

Winsmann et al. [1953] found that an 8-lb laminated nylon armored vest imposed a measurable increase in the metabolic rate of soldiers wearing it over the standard fatigue uniform and walking on level or sloping terrain. These increases in metabolism became greater as activity level and steepness of terrain increased. Goldman [1965] studied the energy expended by heat-acclimatized soldiers on maneuvers in Panama. The soldiers all wore the current standard chemical-biological protective uniform, consisting of gas mask, chemically impregnated long underwear, and an impregnated fatigue jacket and trousers. Goldman believes that the impregnation limited the evaporation of sweat, thereby resulting in an elevation of the body core temperature and possibly a temperature-induced increase in metabolic rate.

Hanson [1961] studied eight matched pairs of Negro and White soldiers in a hot-desert environment under the eight combinations of environmental exposure (shade or direct sun), attire (clothed or clothed and wearing an 8-lb armored vest), and activity level (resting or walking). When the subjects wore the armored vest, sweat production increased progressively as exposure increased from shade to sun or from rest to exercise, while sweat evaporation decreased. The author concluded that the vest interfered with sweat evaporation, thus creating a heat load on the subject, as rectal temperature and pulse rate also increased significantly.

American Negroes and Whites were also studied by Baker [1958a], under both hot-dry and warm-humid conditions. In the hot-dry environment, subjects were compared while clothed and while nude, walking or resting, in the shade or exposed to the direct sun. The dark skin of the Negro evidently absorbs more heat radiated from the sun than does the lighter Caucasian skin, and this imposes a greater heat load. Clothing apparently mitigates this effect of the sun in hot-dry conditions, for rectal temperature and sweat loss responses indicated that the Negroes were more severely stressed than the Whites when both groups were exposed nude to the sun, but the two groups had about equal tolerance when clothed.

C. Individual Variation

1. Introduction

Individual variability affects not only task performance and subjective feelings, but also the degree of physiological change in response to work. Such indices as respiration and heart rate will vary between well-conditioned and less physically fit individuals performing the same task. Adrenal cortical hormone output and eosinophil level changes in response to combat stress, for example, will also vary among individuals, and the mechanisms behind this are not fully understood as yet. Because of the probability of individual variation affecting the results, samples should be drawn to include as wide a base as possible. The experimental task and its environment should be described in great detail, to account for as many variables as possible.

2. Differences Between the Sexes

Brouha [1960a] states that at a given level of oxygen intake, the heart rate is higher in women than in men and, conversely, for a given heart rate, men achieve a greater oxygen transport than women during submaximal and maximal work; the aerobic capacity being 25 to 30 percent lower in women. At light exercise, 360 kg-m per minute performed on a bicycle ergometer, women had higher heart rates than did men, though their recovery processes were quite similar. During heavier exercise, 540 or 720 kg-m/min, the heart rates of women were markedly higher than men, and their recovery to the pre-exercise level was slower. Heart rates (and by inference, cardiac output) increased roughly in proportion to the work done for both sexes, but exhaustion was reached at a lower work load for women than for men.

When 17 women and 30 men walked at 3.5 mph for 15 min on a treadmill with an 8.6 percent grade Brouha [1960a], the men exhibited lower ventilation in cm^3/min/kg of body weight, lower blood lactate, and lower pulse rates. Oxygen consumption by body weight, blood sugar, and respiration quotient were nearly the same for both sexes. When the same subjects ran at 7 mph on an 8.6 percent grade treadmill until exhausted, the men ran twice as long as the women (mean of 216 s for men, 108 s for women). The men were able to reach a greater ventilation, higher respiratory quotient, and markedly greater maximum oxygen consumption; and were, therefore, able to carry on for a longer time. The means and extremes for maximum heart rate were almost identical, but the women reached the maximum in half as much time as the men, and were 11 beats/min faster than the men at the end of 1 min.

A group of elderly men and women in good health were tested on a bicycle ergometer in an environmental chamber at 92° F. dry-bulb, 82° F. wet-bulb [Henschel et al., 1967]. The individuals worked at 10, 20, 30, and 40-W levels in succession, with short rests in between. Females displayed higher pulse rates and oxygen consumption per kilogram of body weight at 30- and 40-W work levels than did the males. Ayoub and Manuel [1966] found no significant difference between 8 males and 8 females aged 20 ± 2 years in ventilation rate either when at rest or while performing light tasks at varying paces. In a second study of 108 subjects (half male and half female, ages 20, 30, or 40) filling a pinboard and dealing cards at various paces, it was found, however, that ventilation rate compared by body surface area averaged 9.6 percent greater for males than females.

In a study of the effects of positive and negative ionization on the performance of college students on a step test, DeVries and Klaffs [1965] found that the ions did not affect males and females differentially. No significant differences either were found between the sexes by Botwinick and Shock [1952] for the slope of output curves of speed and errors when doing speed paper and pencil tasks.

Patel and Grant [1964] tested 120 male and 120 female college students for 3 degrees of distribution of practice and 4 levels of effort required to depress response keys on the Multiple Serial Discrimeter. After a series of practice trials, the subjects rested and then were tested again. The results indicated that: (a) Post-rest recovery of decrements accumulated during learning trials was greater on the average for women. (b) Women showed less recovery following distributed practice at lower effort levels—attributed to differential tolerance of effort by men and women. (c)

Men showed greater warm-up effect following the two lower levels of effort, and women showed greater warm-up effect after practice at the two higher levels. (d) Although there were no significant simple sex differences in overall pre- and post-rest performance, it was found that women were superior in the earlier stages of training, while men became progressively more superior in the later stages of pre-rest learning and post-rest performance. (e) With the greatest level of distribution of practice, men and women showed equal recovery at the highest level of effort.

Pierson and Lockhart [1964] studied 15 female college students (mean age 19.5 years) for reaction and movement (arm movement) times. The results were compared with Pierson's earlier [1963] study of 26 male students (mean age 28.6 years.) Normal, unfatigued, reaction time scores were not significantly different between the sexes, but normal movement time scores of females were significantly slower than those of the males. For men, there was a significant relationship between onset of subjective fatigue and reaction time performance, but not for movement time performance. In females, occurrence of subjective fatigue was significantly related to isotonic endurance and to both reaction time and movement time scores under fatigued conditions. The authors concluded that: (a) men are faster than women in speed of arm movement, but not in reaction time to a visual stimulus; and (b) men can perform a simple repetitive task for a longer period of time than women, but there is no difference in their subjective opinion as to when their performances are becoming slower. The nine-year mean age difference between the males and females studied here must be considered when evaluating these results.

Twelve female and 15 male college students were tested [Whittenburg 1953] for a continuous 2-hr session (after a practice period) on the Mackworth clock test. Errors of omission increased significantly after the first half-hour for both men and women. During the last hour, females made significantly fewer errors of omission than males. Errors of omission proved to be a relatively reliable measure for males, but not for females. The relationship between errors of omission and response time appeared to be stronger for males than for females.

Spaulding [1964] describes an excellent clinical study of 4,000 consecutive medical out-patients at a clinic in Toronto. Fatigue was defined as "a feeling of difficulty in doing things." Although 51 percent of all the patients were men, of the 280 patients who gave "fatigue" as their prime complaint, 63 percent were women. Griffith et al. [1950] gave a Kerr "tear-ballot" subjective checklist to manual laborers, foremen, and office workers each half-hour of their working day. Although the study was poorly controlled, it appeared that females tended to report greater extremes of tiredness than did males.

3. The Effects of Age

D. B. Dill [1961] describes responses of his cardiovascular system to exhausting work on the bicycle ergometer and treadmill from age 37 to age 70. His maximum heart rate on the bicycle declined from 172 beats/min at age 37 to 162 at age 50, 160 at age 60, and 150 at 70 years of age. Work to exhaustion on the bicycle at age 41 ended at 15 min, with a pulse rate of about 165 and oxygen consumption of 2.75 liters/min; while at age 70, exercise could be continued for only 7 min, attaining a pulse of 150 and oxygen consumption of 1.96 liters/min. On the Balke treadmill test at age 66, Dill became exhausted at 15 min, with a final pulse of 160 and oxygen consumption of 2.75 liters/min. At age 67, after dieting from 80 to 72 kg, Dill's limit was 17 min, with a pulse of 160 and oxygen consumption of 2.6 liters/min. At age 68, he lasted for 16 min, with a final pulse of 160 and oxygen consumption of 2.5 liters/min. At 70 years of age, Dill walked for 16 min; however, his maximal heart rate was 150 and oxygen consumption was 2.3 liters/min.

A study mentioned by Brouha [1960f] of 1510 employees performing the same task, involving heavy physical labor in combination with exposure to heat, showed that the pulse rate of workers aged 40 to 50 years averaged 10 beats/min faster during post-work recovery than that of workers aged 20 to 40. In an experiment by Henschel et al. [1967], 100 elderly volunteers (68 males with a mean age of 72 years and 32 females averaging 69 years) living in St. Petersburg, Florida, exercised on a bicycle ergometer at 92° F. dry-bulb and 82° F. wet-bulb. The subjects were in better than average health for their age and free from active diseases, and they appeared to tolerate the moderate heat-work load without difficulty.

Ayoub and Manuel [1966] compared ventilation rates by a respiration gasometer for 8 males in each of 3 age groups (20 ± 2 years, 30 ± 2 years, and 40 ± 3 years) and 8 females aged 20 ± 2 years. Subjects were measured while at rest and while performing on several different tasks requiring little physical effort. Bartlett's test of homogeneity of variance indicated that, while there were significant differences between subjects within each of the four groups, there were no significant differences between groups. A second experiment used 18 males and 18 females in each of the 3 above age groups, dealing cards and filling a pinboard. No significant interactions were found, and age was apparently not a factor in determining ventilation rate compared by body surface area.

Botwinick and Shock [1952] studied staff and patients from a hospital and patients from a city home for indigent aged. Fifty subjects aged 20 to 29 years and 50 aged 60 to 69 years were tested on speed of (a) writing digits and (b) writing words; addition of (c) 3-digit, (d) 6-digit, (e) 9-digit problems; and (f) digit substitution. Significant age differences ($p < 0.01$) in the decrement relationship of speed of response to continuous repetition of the performed tasks were found in adding 3- and 6-digit problems and in digit substitution. Speed of writing digits increased with successive work units, but there was no significance to the mean increment difference between age groups. Slopes of performance decrement on speed of writing words and on 9-digit addition were significant beyond 0.05. Larger work decrements were made by the younger subjects, but both the initial and final levels of performance in every task (for both total rate and rate of correct response) were greater in the younger group.

In a study of factors associated witb absence rates, Shepherd and Walker [1957] examined employee records of an engineering firm and two iron and steel works. As indices of absence, the authors used the percentage of shifts lost and the number of absences expressed as a percentage of the total number of possible shifts. Absence was lowest among the men in the 35 to 44 age group, being greater in both younger and older groups. The increase among the older men was more marked for lost time rates than for the incidence rates.

Six male subjects from a medical school population, three aged 19 to 23 years and three 40 to 48, took a jet flight from Oklahoma City to Tokyo, rested 10 days, and then returned. The older group reported generally higher levels of fatigue, as measured by a scaled checklist, and also had slower optical reaction times than those of the younger group. In an industrial and office situation [Griffith et al. 1950], older workers were more aware of being tired than were younger workers, as indicated by a Kerr "tear ballot." The average age of the 4,000 medical out-patients studied by Spaulding [1964] was 40 years, and those over 40 had twice the frequency of physical disorders of the younger half. The older patient was also more likely to remain undiagnosed as to the cause of fatigue than was the younger one.

4. Physical Fitness

Patterson et al. [1964] placed several hundred men, aged 18 to 45, in 5 categories of physical fitness based on their previous athletic training. They were then tested on a 20" Harvard step test—first a submaximal step test, then a capacity step (30 steps/min) and a capacity pack (30 steps/min while carrying a load equal to 1/3 of subject's weight.) The submaximal test predicted performance on the capacity tests, using the heart recovery rate as a criterion. Endurance and heart rate were correlated to determine physical fitness. Final physical fitness levels were set by the length of performance on the capacity tests.

Rasch and Wilson [1964] studied the relationship between the U.S. Marine Corps criterion of endurance (running 3 miles in field gear, including weapon and light pack) and 3 tests—Harvard Step Test, Harvard Treadmill, and Balke Treadmill. While the correlation between the Balke test and the 3-mile run was significant beyond the 0.01 level, the two Harvard tests did not correlate significantly with the Marine Corps test. There were also extremely low correlations between the three tests.

Frick and Konttinen [1961] observed cardiodynamic changes in 10 military men, ages 19 to 26, over two months of military training. Subjects were studied while performing in supine position on a bicycle ergometer. The military training resulted in an increase of heart volume and physical working capacity, with a slight increase of the cardiac index at rest, a decrease in pulse rate at rest, and an appreciable increase of the resting stroke value. Left ventricular pressure work remained the same, while left ventricular stroke work greatly increased at rest. The authors concluded that the more physical training an individual has, the less strain there is on the cardiac system.

Kreider et al. [1961] took 19 soldiers on two, 10-day treks on the Greenland icecap at 7,000′ altitude. Subjects walked 8 miles daily, either pulling a load on a sled or a combination of pulling and back-packing; while on either full rations or 60 percent rations. Physical endurance, as measured by the Harvard step test, improved for both ration conditions and over both experimental periods. Volume of inspired oxygen decreased for both ration groups, but dropped lower for the men on reduced rations. The treadmill test and subjective evaluations by the experimenters and by other subjects did not correlate well with the Harvard step test.

Performance on perceptual organization and illusion tasks were tested by Lybrand [1952] with 48 male subjects in 4 conditions: at rest, after a 5-mile hike while carrying a 40-lb pack, after 1 night without sleep, and a combination of the hike and sleep loss. Fatigue induced by marching produced *more* efficient performance on the Kohs Block Designs test. Fatigue induced by sleep loss produced *less* efficient performance on the Perception of Hidden Figures and the Kohs Block Designs.

DuBois [1960] presents a classification of occupations into 10 grades by the degree of physical fitness required. He used two criteria of fitness: (a) the estimation of the total caloric expenditure per day, which was usually obtained indirectly by measuring the food intake of people engaged in these different occupations; and (b) the number of calories expended per minute during performance of the peak task required by the work. The physical fitness grades include:

(1) Bedridden, requiring 1800 to 2200 calories per day, or 1 or 2 cal/min.

(5) Light work by a clerk or executive, utilizing 2200 to 2800 cal/day, 5 cal/min.

(10) Champion athlete in training, expending 3700 to 5200 cal/day, 17 cal/min during peak performance.

Brouha [1960a] believes that the most important factor determining the level of physiological reactions to exercise is an individual's fitness. Brouha lists the following as being among those responses which differentiate the fit from the unfit:

"(1) More economical ventilation during exertion;
(2) Ability to attain a greater maximum ventilation;
(3) Greater mechanical efficiency as measured in terms of lower oxygen consumption for a given amount of external work;
(4) Ability to attain a greater maximum oxygen consumption;

(5) Lower gross respiratory quotient (R.Q.) during exercise;
(6) Lower blood lactate for a given amount of exercise;
(7) Ability to push self to a higher lactate before exhaustion;
(8) Less increase in pulse rate for submaximal exertion;
(9) Quicker recovery in pulse rate following activity;
(10) Ability for the fit and the unfit to attain the same maximum heart rate, but the fit subject performing more work before reaching that level."

5. Intelligence

Auxter [1966] compared the ability to withstand the onset of muscular fatigue, as measured by grip strength, among intellectually typical and mentally retarded boys differentially diagnosed as brain-damaged, non-brain-damaged, and undifferentiated. The boys' ages ranged from 9 to 11 years, and grip strength was measured by a hand dynamometer. Analysis of variance among the four groups was significant ($p < 0.01$). T-tests between the intellectually typical group and the three groups of retarded boys were also significant beyond 0.01. The non-brain-damaged group performed significantly better ($p < 0.01$) than both the brain-damaged and the undifferentiated groups, while no significant differences were found between the latter two groups.

The study by Botwinick and Shock [1952] of age differences in decrement of response to repetition of paper and pencil tasks included controls for education level. Two groups of subjects were used, one group of 50, aged 20 to 29 years, and another 50 people, 60 to 69 years old. All were Caucasians, born in English-speaking countries, and had a minimum of four years of formal education. Larger decrements were made by the younger subjects, but their initial and final levels were greater than the older ones. Controlling for differences in education level indicated that the higher educational level of the younger population was not responsible for their larger performance decrements.

Colquhoun [1959] investigated the efficiency of machine-paced inspection of small items for deviations. The subjects were 32 young U.S. Navy ratings, and differences in their individual checking efficiency were found to be not related to intelligence as measured by Hei. s test.

6. Nutrition

In the study by Kreider et al. [1961], of load transport on the Greenland icecap 7,000 ft above sea level, two diet conditions were compared: full rations (about 4800 cal/day) and a reduced ration (approximately 60 percent of the full ration, or about 2900 cal-/day). Subjects went on two 10-day treks separated by a 7-day rest period, with half the subjects on each diet condition during the first trek and then switching conditions for the second trek. Body weights fell an average of 1.6 kg in the first trek and 1.8 kg in the second for the men on full rations, and 2.7 kg and 3.8 kg for the subjects on reduced rations. Performance on the Harvard step test improved for both ration conditions. Volume of oxygen intake decreased for both ration groups, but dropped lower for men on the reduced ration, even when plotted by body weight.

Mack and Dixon [1955] studied the effects of a glass of orange juice given to children in the morning after an overnight fast. Children were given one of four strength or manual tests, then ingested a glass of orange juice or colored water, and then repeated the test 15 min after drinking. Response changes tended to favor orange juice over the control drink. There was no significant difference in the average change for the hand manometer test; but the change in push-up and sit-up performance following orange juice surpassed ($p < 0.01$) the change following the control drink. No significant difference was found for the percentage change in pulse rate after doing 30 steps/min for 5 min. Average time change in Minnesota Form Board tests were more favorable for the orange juice ($p < 0.05$). In another study using the above tests except for sit-ups, and with double-strength orange juice, results favoring orange juice were significant (< 0.01 or 0.05) for all tests except the manometer.

Shaw et al. [1962] tested 163 medical patients who complained of general fatigue, with potassium and magnesium salts of aspartic acid and a placebo. Subjective and objective relief of fatigue is reported to have occurred. A similar experiment was conducted by Taylor [1961] with 92 members of a health service plan who complained of persistent fatigue. These subjects were also treated with potassium and magnesium salts of aspartic acid and a placebo for six weeks. The results were positive in 80 percent of the trials with the drug, and questionable to positive in only 9 percent with the placebo.

Todd and Allen [1960] studied the effects of glycine on cold exposure of rats. Rats fed a diet containing 10 percent glycine maintained carbohydrate stores during a cold stress of 8°C. for 1 to 12 hr at a higher level than did animals prefed the same diet without the amino acid.

Brouha [1960a] states that "Cases of malnutrition are more common than generally realized even by the medical profession." A survey of 110 industrial workers mentioned by Brouha [1960a] indicated that, while their diet was satisfactory in calories, proteins, and vitamins, it was deficient in thiamine, riboflavin, nicotinic acid, ascorbic acid, and vitamins B and C.

7. Acclimatization

Strydom and Wyndham [1963] tested members of various ethnic groups on a step test under warm-humid conditions. Acclimatized Caucasians appeared to do about as well as natives of the Tropics. Relatively inactive Caucasian South Africans had significantly higher rectal temperatures and pulse rates during exercise than did Bantu, accustomed to continuous work.

These differences appeared to disappear after acclimatization (the process of acclimatization used in the study was not specified). For example, only half of the unacclimatized white South Africans lasted for 4 hr on the step test, and these ended with a mean rectal temperature of 103.7° F., while acclimatized South Africans and acclimatized Bantu had the lowest temperatures—101.0 and 100.7° F., respectively. Australian Aborigines, Chaamba Arabs, Bantu, and River and Kalahari Desert Bushmen all responded similarly to each other, obtaining intermediate values.

Mean pulse rates ranged from 122.3 beats/min for acclimatized Bantu to 173.6 for Caucasian South Africans. The sweat rate of unacclimatized subjects decreased with time to such an extent that their skins appeared dry, but were actually still clammy to the touch. The Arabs and Desert Bushmen had significantly higher sweat rates than natives of tropical and temperate regions.

8. Racial Factors

Hanson [1961] compared eight matched Negro-White pairs of men under combinations of these conditions: walking or resting, in the shade or in the sun (hot-dry desert environment), and clothed or clothed and wearing an armored vest. Variance analysis of measures of sweat production, sweat evaporation, and rectal temperature revealed no significant differences between Negroes and Whites. These data agree fairly well with P. T. Baker's [1958a] results for clothed subjects in hot-dry desert. Baker studied 40 matched Negro-White pairs under warm-humid conditions and 8 pairs in hot-dry. Recordings were made of pulse rate, rectal temperature, and sweat loss (by body weight changes). In the warm-humid condition, Negroes had a higher physiological tolerance than Whites for walking while clothed. In hot-dry nude-exposed-to-sun conditions, suntanned Whites had a higher tolerance. Negroes and Whites had about equal responses in all other conditions.

From the results of such studies as the above, Baker [1958b] derived a theoretical model for men living in hot desert conditions. The ideal man would be healthy, have a low amount of subcutaneous fat, have a large surface area to weight ratio, have brunette skin color, and be acclimatized to a high level. This model appears to conform well to the populations now living in desert areas throughout the world.

Johnson and Corah [1963] describe independently obtained findings on basal skin resistance. One study compared 65 White and 22 Negro boys and 55 White and 32 Negro girls, about 7 or 8 years old. Mean Negro skin resistance was approximately 40,000 Ω above that of the White children. Analysis of variance indicated that the race factor was significant beyond the 0.001 level. The second study compared 16 Negro and 16 White men and 5 Negro and 5 White women, ranging in age from 18 to 39. Mean skin resistance levels were 171,000 Ω for Whites and 373,000 Ω for Negroes, a difference significant beyond 0.001. There were no significant differences between the races in EEG amplitude, heart rate, respiration rate, skin temperature, spontaneous GSR activity, diastolic and systolic blood pressure, manifest anxiety, or any of the autonomic responses to the buzzer. These differences may be caused by a difference in the number of active eccrine sweat glands or by the thicker stratum corneum of Negro skin.

9. Training

More quantitative research is needed on the subject of what happens during training for industrial tasks involving manual labor, and why. Brouha [1960a] states that training increases the size of skeletal muscles, improves the transmission of nerve impulses to the motor units as well as the precision and economy of any motion or sequence of motions, increases the efficiency of the heart, affects the blood pressure, improves cardiovascular recovery processes, modifies the blood distribution and changes respiratory responses. After a few weeks of training, improvement ceases and performance levels off. If the work rate is increased, performance will rise to a new and higher plateau. This can be repeated several times before the maximum is reached.

10. Personality

In Spaulding's [1964] study of medical out-patients at a Toronto clinic, "fatigue" was the chief complaint of seven percent of the patients, ranking fifth in prevalence. Fifty percent of the causes of fatigue were psychiatric disorders, usually (68%) an anxiety state, and less commonly (13%) a depression. Similar results were reported by Shands and Finesinger [1949] in 100 interviews and free-associations of psychiatric patients who complained of chronic fatigue in the absence of exertion or medical disease. In all of the patients a diagnosis of some type of psychoneurosis was made, most commonly (62%) a neurosis associated with anxiety symptoms. Hysteria was the primary diagnosis in 19 cases, and reactive depression in 9, although depression was seen to some degree in nearly all patients. Psychoneurotic fatigue was seen to be a disease of those individuals whose major preoccupations were anticipatory. The authors believe that fatigue can be explained most satisfactorily as the conscious manifestation of a defensive inhibition of overt aggressive activity, rather than as the result of energy consumption in the past.

Schwab and Brazier [1958] found that 20 normal (control) seaman performed 10 to 25 percent better on a 1-min step test than 20 psychiatric patients did. Normals also endured for 40 to 80 s (mean of about 60 s) on a hanging-bar test, while psychiatric patients averaged only 40 to 50 s. When corrected for time differences, the patients' average lactic acid level was slightly higher than that of the normals. Electromyograms, however, were nearly the same for both groups on the hanging-bar test.

Colquhoun [1959] investigated simple, machine-paced checking work done by 32 young seamen. Differences in individual checking efficiency were unrelated to temperament as indicated by scores on Part I (emotional instability) and Part II (unsociability) of the Heron test.

Hanes and Flippo [1963] divided students by the IPAT Self Analysis Form into "low anxiety" (the lowest three deciles, with 20 subjects) and "high anxiety (the upper three deciles, with 17 students). Subjects worked on a modified Barnes Pegboard mounted high to induce muscular strain, for as rapidly and as long as possible. The low anxiety group completed an average of 35.8 units (1 unit = 1 column of 6 holes), while members of the high anxiety group completed only 24.65 units. T-test indicated that the difference between the means was significant at 0.01. The time taken to complete a work unit was the same for members of each group, and did not increase as the test period progressed. While 70 percent of the high anxiety group reported feelings of fatigue by the tenth work unit, only 10 percent of the low anxiety group did so by that time.

11. Motivation

Benson and Dearnaley [1959a] found that offering a prize to subjects increased the length of time they could pull a double-handled isometric strain gage. The rate of increase in electromyographic activity of the gastrocnemius soleus muscle group was also greater under competitive conditions.

Payne and Hauty [1953] varied motivational and pharmacological treatment levels in their study of Air Force personnel doing a perceptual-motor task with simulated aircraft instruments and controls. The motivational treatment consisted of indoctrinating the subjects to different levels as to the purported significance of the experiment to Air Force operations. While very substantial performance differences were related to the pharmacological treatments (various analeptic and sedative drugs), no significant differences could be attributed to the motivational conditions. The greater motivational level was associated with more favorable attitudes toward the task than was the lesser condition, but there was no significant relationship between attitudes and performance.

Another experiment by Payne and Hauty [1955], on the USAF School of Aviation Medicine Multidimensional Pursuit Test, used analeptic drugs and three levels of motivational feedback: giving the subject a hazy notion of his performance, giving the results of the trial just completed, and keeping the results of the entire performance constantly in the subject's view. A trend indicated an inverse relationship between motivational level and work decrement. Disposition to the task was reported to be generally improved by dexedrine, and impaired by benadryl-hyoscine.

The performance of high school and college students on arithmetic tasks with observations of flicker fusion frequency was studied by Wendt [1953]. The author concluded that motivation and performance were positively correlated. The subjects with low motivation improved their performance on those tasks which were paced or scheduled. The critical flicker fusion frequency dropped more for the less motivated subjects, as the more motivated subjects apparently directed more attention and effort to their tasks. Motivated subjects performed best on unscheduled tasks, their productivity dropping closer to that of the unmotivated group under conditions of pacing. Accuracy was higher in all cases for the more motivated group. Wendt concluded that the use of flicker fusion frequency as a criterion of fatigue should be restricted to situations involving little or no motivation, so that adaptive physiological mechanisms will not be energized.

There are, of course, many other variables which may be expected to differentially affect individuals' attitudes and performance. Some of these are difficult to quantify, and most have not been assessed specifically for their effects on task performance in an experimental situation. These include such factors as a worker's state of health; body size, composition, and shape; ethnic-group identity as perceived by self and by others; family situation; amount of average daily rest and sleep; form and amount of recreation; and moonlighting.

IV. Dependent Variables

A. Physiological Variables

1. Heart or Pulse Rate

An individual's heart rate, usually expressed as the number of beats per minute, is a valuable indicator of the physiological cost of work. It is sensitive to light work as well as to heavy physical exertion, and is often capable of differentiating between the sexes and between members of different ethnic groups. Heart rate is most commonly and easily measured by palpating the wrist immediately after work periods. Electrocardiographs have been used to monitor or record heart rate continuously [Astrand and Saltin 1961; Sharkey et al., 1966]. A vectocardiograph, measuring the spread of electrical excitation over the heart muscle, has been developed for a study of the inflight performance of jet pilots over Vietnam [Plattner 1967].

Glassner and Peters [1959] sampled heart rate every three seconds from cardiotachometer readings. The difference between successive readings, or the pulse rate deviation, was used as a measure of physiological activity during performance of mental tasks. In general, the activity level was inversely related to the task difficulty level, leading the authors to conclude that physiological responses were suppressed. Ekey and Hall [1961] also used a cardiotachometer, with chest electrodes, to measure the heart rate of subjects while they were performing on bicycle and torsion-bar ergometers. Heart rate appeared to be more sensitive than blood pressure, electrical skin resistance, or heart sound to the physiological costs of work at different output levels.

An ingenious device for continuously recording the pulse rate was developed by Müller and Reeh [1955]. A photoelectric cell and lamp clamped to the earlobe measures changes in translucency of the earlobe as a pulse of blood flows through. The output can be recorded either by a counter or as a toothed curve on paper.

Sharkey et al. [1966] used a radiocardiograph transmitter and a remote receiving recorder to monitor the heart rate of subjects walking a treadmill. Data on heart rate and ventilation rate from the treadmill performance were used to predict energy costs (oxygen consumption) of various other physical exercises. Ventilation rate was found to be a better predictor, as the pulse rate data overestimated oxygen consumption in all the cases tested.

In Christensen's analysis [1953] of several different jobs at an iron foundry, pulse rate, oxygen consumption, body heat production, and body temperature were all recorded. The greatest values for each measure were found on different activities, indicating that these measures do not always correlate well with each other.

The study by Henschel et al. [1967] illustrates a difference between the sexes in pulse rate response to exercise. Elderly females had a faster pulse than did elderly males, when corrected for body weight, at high work levels on a bicycle ergometer. These subjects were tested in both summer and a moderate winter at St. Petersburg, Fla. There was no difference between resting pulse rates for the two seasons, but the value during physical exercise was higher in the winter than in the summer. The reverse was found by Strydom and Wyndham [1963], with River Bushmen reaching a higher pulse rate in the summer than in the winter when exercising on a step test.

The rate at which the pulse or heart rate returns to pre-exercise levels following work has been shown by several investigators to be a valuable measure of physiological cost and debt. Domanski et al. [1951] determined that pulse rate recoveries following treadmill exercise were related to the extent of the antecedent displacement of the resting pulse rate. Young [1956] found very high positive correlations between pace of work on various physical exercise tasks and the heart rate taken immediately following work. Heart-rate recovery curves following work at different paces sometimes crossed—indicating for some tasks a faster recovery after work at a high pace than that following more slowly paced exercise. Two groups of manual laborers, one group exposed to nitroglycerine and the other not, had the same average heart rate 1 min after work [Zapp, 1960]. During a 15-min recovery period, however, the exposed group's mean heart rate was higher than that of the control subjects. From studies of short. repeated periods of heavy industrial work, Brouha [1960d] concluded that when the average value of the first recovery pulse is maintained at or below 110 beats per minute, and when the deceleration from the first to the third minute is at least 10 beats per minute, no increasing cardiac strain occurs as the working day progresses.

Bitterman and Soloway [1946] compared the performance of 10 subjects working on clerical tests while a voice was reciting numbers at 60 dB sound level and during relative silence. Neither accuracy of test scores nor eye blink rate changed with the change in conditions. Heart rate, however, increased significantly during the noise—an indication perhaps of increased muscle strain as a result of increased efforts to concentrate. In another task involving a minimum of physical exertion, Geldreich [1953] found that heart rates were significantly faster when subjects responded to a random presentation of four colors by pressing the appropriate one of four keys than when they only tapped the keys or just watched the colors. Heart rate, along with respiration rate and galvanic skin resistance, was positively correlated to the speed of response to the colors and negatively correlated to the frequency of blocking.

In a study of airline pilots on transatlantic flights, the British Flying Personnel Research Committee [1965] discovered that all subjects experienced a rise in heart rate on takeoff and a generally greater (sometimes to above 140 beats per minute) and more prolonged rise during descent and landing. Throughout a flight, recorded peaks of faster heart rate were usually synchronous with an observer's notation of periods of greater pilot activity, such as position reporting, eating breakfast, or encountering turbulence. Roman, as reported by Plattner [1967], used an electroencephalograph with three dry electrodes to record heart rates of aircraft carrier pilots on combat flights over Vietnam. Heart rates were found to be "substantially higher" during launching and recovery periods than during bomb runs under antiaircraft fire. Subjective reports by the pilots verified the existence of this difference in stress levels. Heart rates were lower on the second mission of the day than on the first. The average heart rate during a flight was lower than the experimenter anticipated—87.6 beats per minute. Heart rate also correlated strongly with measured landing error.

Shannon [1966] describes a study in which six men went on a 10-mile 2-hr hike on each of five successive days. The mean pre-walk pulse rate was 79.2 beats per minute, significantly lower than the mean rate of 104.4 after walking 2.5 miles. Pulse rates measured at 5, 7.5, and 10 miles each day were not significantly different from that at 2.5 miles. While saliva composition and rate of flow did not change significantly over the 5-day test period, both pulse rate and body weight did.

Balke [1954a] found pulse rate to be directly related to increased work load (pitch increase) on a treadmill.

Several studies have used pulse rate as a measure of the effects of heat stress on an individual's performance and on the performance of members of different ethnic groups. Strydom and Wyndham [1963] subjected male subjects from 11 different ethnic groups to a standardized step test in warm-humid conditions. Subjects worked for 4 hr, unless overcome by exhaustion before then, and pulse rates were taken by wrist palpitation at rest and at the end of each hour's exercise. At the end of the fourth hour, mean pulse rates ranged from 122.3 beats per minute for acclimatized Bantu to 173.6 beats per minute for Caucasian South Africans (half of the South Africans were unable to work for 4 hr). Pulse rates of Bushmen and Bantu showed a distinct leveling off after two hours of work, and none of the acclimatized Bantu exceeded 150 beats per minute. Baker [1958a] found no significant difference for pulse rate between American Negroes and whites walking in a warm-humid environment. Rectal temperatures, however, were significantly different ($p < 0.01$). In a hot-dry environment, under the combinations of direct sun or shade, walking or resting, and nude or clothed, Negro and white soldiers differed in initial and final rectal temperatures, but not in pulse rate or sweat loss.

Brouha [1960c] found that heart rates were greater for subjects exercising on a bicycle ergometer in both warm-dry and warm-humid conditions than in "normal" atmospheric conditions. During 10, 5-min rides on the bicycle with partial heart-rate recovery in between, subjects' heart rate and recovery rates both increased from the first to the tenth cycle, and no steady state could be maintained. Brouha [1960e] also studied six male subjects walking treadmills in warm and cool workrooms alternately with less than 30 s in between. On the basis of the maximum heart rate obtained during work, the stress was similar whether the subject went from cool to warm or from warm to cool conditions. The cardiac debt, however, was 39 percent smaller when the work cycle progressed from warm to cool conditions, and the heart-rate recovery was faster.

Brouha and Maxfield [1962] observed two subjects pedaling bicycle ergometers in comfortable and warm-humid conditions. Subjects exercised for 8 or 10, 5-min periods with intervening rest periods just long enough to permit oxygen consumption to return to the pre-exercise resting level. While oxygen consumption behaved similarly in the two conditions, heart rate attained a steady state in the comfortable environment, but in the warm-humid condition it increased during each work period and ended at progressively higher levels with each successive cycle.

2. Electrocardiogram

Electrocardiographic equipment has been used in studies of human performance primarily as a means of continuous recording of heart rate [cf Astrand and Saltin, 1961; Nagle et al., 1963, 1966]. Henschel et al. [1967] used a 12-lead EKG to determine the physical fitness of elderly subjects before subjecting them to a physical exercise program. A radiocardiograph was used by Sharkey et al [1966], to transmit heart rates of subjects performing on various exercises. Plattner [1967] states that NASA's Flight Research Center is developing a vectocardiograph, consisting of a jacket worn by the subject, containing conductive pads to present a three-dimensional analysis of the spread of electrical excitation over the heart muscle.

3. Heart Sound

Ekey and Hall [1961] recorded heart sound by a microphone placed over the apex of the heart of subjects performing on bicycle and torsion-bar ergometers. The data recorded when the subjects exercised strenuously were not usable because of extraneous sound artifacts. Heart sound was also not found to be an homogeneous predictor among subjects tested with mild exercise.

4. Metabolic Rate

Daniels et al. [1953] compared two methods of measuring metabolic rates of subjects walking on a treadmill—a closed-system Tissot spirometer and the Haldane method of analyzing air collected in Douglas bags—and found no significant difference between them. The two methods were then used to compare energy costs of pack-carrying on a treadmill and while walking outdoors on pavement and on a cinder track. Metabolic rates expressed in cm^3 of oxygen consumed per minute and as calories per square meter of body surface area per hour indicated that carrying a load while walking outdoors required an average energy expenditure 9 to 10 percent greater than while walking at the same rate and carrying the same load on a treadmill. The authors suggest that the body mechanics of walking a treadmill may differ from those of walking under normal conditions. Winsmann et al. [1953], using the same methods as Daniels et al., compared load carrying on a treadmill, outdoor cinder track, and mountain slopes. They found that wearing an armored vest over normal clothing imposed a measurable increase in the metabolic rate. Increases in metabolic rate became greater as steepness of mountain slope increased, especially at high activity levels.

A Müller-Franz respiratory air meter was used by Goldman [1965] to take timed respiration volume measurements of soldiers on maneuvers. Caloric expenditure was then calculated from the oxygen content of the expired air. The upper range of the rate of energy expenditure was 6.7 to 7.5 kg cal per minute. Since the troops were permitted to work at their own pace, the energy cost values obtained were independent of terrain. The relationship between ventilation volume and energy expenditure was determined to be linear, indicating that a calculation of energy cost might be made by using a formula to convert ventilation volume. Christensen [1953], in a study of workers at an iron foundry, found that the greatest mean value for body heat production (11.6 cal/min) occurred in workers performing the same activity (open hearth slag removal) in which the greatest mean oxygen consumption (2.39 l/min) occurred.

5. Respiration Rate and Volume

Ayoub and Manuel [1966] measured respiration rates of subjects wearing a respiration gasometer. The relationship between ventilation rate (expired pulmonary air in liters per minute) and pace of work on two repetitive sedentary tasks was not found to be linear. No significant differences in ventilation rates were found between males aged 20, 30, and 40 years or between males and females aged 20 when seated at rest. Glassner and Peters [1959] selected mental tasks of varying difficulty from the U.S. Army General Classification Test. Subjects' respiration rates were measured by counting the number of inhalation-expiration cycles per minute, and respiratory amplitude was determined by a spring-loaded sliding potentiometer placed across the chest. A respiratory index was determined by multiplying the respiration rate by the amplitude. This index and also pulse rate and skin resistance varied inversely with task difficulty. Several measures made by the British Flying Personnel Research Committee [1965] of transatlantic commercial jet pilots in flight indicated the unexceptional nature of the work load. Respiratory end-tidal samples taken on the runway immediately after flights confirmed thy by indicating that the pilots had not been hyperventilating.

As described above, Goldman [1965] used a Müller-Franz respiratory air meter to take timed respiration volume measurements of infantry on maneuvers. Kreider et al. [1961], for a study of load transport by humans on the Greenland icecap, developed a respiratory air measurement device consisting of a small turbine wheel inserted into the air intake of a gas mask. The turbine was geared to a revolution counter, and since the mass of air passed each revolution was known, the volume of air inhaled could be determined by reading the counter at intervals. Work on the icecap was performed at an altitude of 7,000 ft, and the respiratory volume was found to increase about 8 percent over the average value at sea level. Upon subjects' return to sea level, the volume of inspired air during performance of a mild step test remained high for at least 12 days, but dropped to the normal sea-level value at 19 days.

Balke [1954a] studied treadmill walking at different angles of slope. He found that pulmonary ventilation increased more rapidly with increasing work load than did oxygen consumption, indicating a decrease of ventilatory efficiency. Consolazio et al. [1963] examined respiratory quotients, maximum breathing capacity, vital capacity and metabolic rate in a study of the effects of "spartase" on treadmill performance, and found no significant effects. Sharkey et al. [1966] recorded ventilation rates, oxygen consumption, and pulse rates of subjects walking on treadmills at various work loads. Regression equations were used to predict oxygen consumption during performance of other tasks from the pulse and ventilation rate data obtained from the treadmill. Ventilation rate proved to be the more accurate predictor of oxygen consumption.

In a study of human performance under varying work loads on a bicycle ergometer, Astrand and Saltin [1961] collected expired air in Douglas bags and measured its volume in a balanced spirometer. They found that, as work load increased, the maximal ventilation increased and the pulmonary ventilation increased more rapidly. This measure appeared to differentiate the varying work loads better than heart rate or oxygen uptake for the first two or three minutes of exercise. In another study of performance on the bicycle ergometer, Henschel, et al. [1967] measured ventilation rate and volume with an Edwards mask and dry gas meter. Ventilation volume was found to increase consistently with work load, age (all subjects were elderly), and with ambient temperature.

Hauty and Adams [1965b] investigated circadian rhythm shifts as a result of jet flights from Oklahoma City to Manila and return. Respiratory rates were recorded five times a day by a chest strap housing a mercury-in-rubber strain gauge to measure changes in chest circumference. No well-defined or consistent periodicity appeared in the respiratory rate.

6. Oxygen Consumption

Brouha and Maxfield [1962] used an analog computer to provide a continuous record of oxygen consumption measured by a pneumotachometer and an oxygen and carbon dioxide analyzer. Two men were observed exercising on bicycle ergometers in comfortable and warm-humid atmospheres. While oxygen consumption curves behaved similarly in the two conditions, heart rate changes differed markedly. Seasonal changes in oxygen intake were found by Henschel et al. [1967], for elderly people working on a bicycle ergometer during a mild winter and a hot humid summer. As measured by a Bechman paramagnetic analyzer, both total oxygen consumption and oxygen consumption corrected by body weight were higher in the winter than in the summer. The authors conjectured that the subjects may have been engaged in more outdoor activity during the summer, and thus in better physical condition at that time.

Winsmann et al. [1956] measured oxygen consumption with a closed-system Tissot spirometer for subjects walking on a treadmill and with Douglas bags for subjects walking outdoors. Wearing an 8-lb armored vest imposed a measurable increase in metabolic rate, which became greater as steepness of slope of the walking surface increased. In the study by Kreider et al. [1961], of load carrying in the Arctic, oxygen cost was greater when a subject carried part of a load on his back and pulled the rest on a sled than when the entire load was on the sled.

Two subjects were tested [Noltie, 1953] while running for 3 miles a 7.5 mph, with or without a previous limbering-up ½-mile run at 6 mph. For both subjects, the oxygen debt of the combined run and limber-up was greater than that for the run alone, but it was less than the sum of the two separate debts. The oxygen uptake at the start of the 3-mile run was higher if the subject first limbered up, but the steady state values for the rest of the run were not appreciably altered. As the oxygen debts were not simply additive, the author concluded that the other benefits of limbering-up could be secured without the handicap of reaching the subject's maximum tolerated oxygen debt as quickly as if the debts were additive. Small sample size, infrequent oxygen sampling, and limited statistical analysis, however, leave the results open to question.

Sharkey et al. [1966] attempted to predict the oxygen consumption of four subjects exercising at various tasks by using regression equations computed from pulse rate and ventilation rate data acquired from the same subjects while walking on a treadmill. Greater accuracy in prediction was obtained with the ventilation rate data, and greater precision resulted when the task was most nearly similar to the activity used to derive the prediction equation. In other words, the form of the exercise used seems to influence the form of the physiological demand on the subject.

Douglas bags were used by Walk and Sasaki [1965] to study short-term rowing during 4 gravity conditions from 0 to 2G obtained in airplane flights. Gross differences in oxygen volume at rest, during work, and in recovery indicated that the body reacts to a change in physical activity and returns to a state of equilibrium very quickly. The volume of oxygen consumed was similar in each of the 4 gravity conditions.

7. Carbon Dioxide Output

Volumes of CO_2 were also similar during the rowing exercise under the 4 gravity conditions [Walk and Sasaki, 1965]: Changes in CO_2 during rest, brief violent activity, and recovery paralleled those in oxygen consumption.

8. Blood and Pulse Pressure

Nagle et al. [1966] compared blood pressure measures obtained simultaneously by auscultation of the brachial artery and by right-side cardiac catheterization and retrograde supra-aortic catheterization. Two male subjects were measured while lying down, sitting, and at four levels of exercise on a bicycle ergometer. The systolic pressures measured by auscultation generally agreed with those recorded by catheterization. The auscultatory diastolic pressures, however, were consistently higher than the directly recorded values for one subject, and consistently lower for the other subject. Diastolic measures obtained by auscultation during exercise should be used with caution.

Dill [1961:1028] observed the method used by Balke and Ware to record blood pressure during the Balke treadmill test: "The cuff is held in place with elastic tape and is inflated once a minute; the diaphragm of the apparatus is secured in place over the brachial artery and the tubes are not allowed to swing against the body or treadmill supports. The systolic pressure is read during the first 15 s of each minute; as the pressure drops the pulse in counted for 15 s, after which the diastolic pressure is read." This method of measurement has been compared with a simultaneous recording of the pressure of the radial artery of the other arm using an indwelling catheter and strain gauge, and the two techniques compared satisfactorily. Dill walked Balke's treadmill on several occasions to exhaustion (usually achieved in 14 or 15 min) on a steadily increasing angle. While Dill's heart rate increased linearly and steadily, his systolic pressure increased in stages, and the diastolic remained steady until the final 2 min, when it increased 10 points. Dill also reports that, for one athlete walking a treadmill, the systolic pressure did not increase greatly until his oxygen consumption had reached 2 liters per minute.

Balke [1954a] reports for five men walking a treadmill at various percentages of their "optimum work capacity" that systolic pressure increased linearly with time, but values were lower as the effects of the preceding work load were higher. Again, diastolic pressures remained practically unchanged throughout the test sessions.

Pulse pressure (the difference between systolic and diastolic blood pressures) was found by Ekey and Hall [1961] to be very sensitive and capable of discriminating among strenuous task levels as the heart rate approached a maximum during exercise on bicycle or torsion-bar ergometers. Diastolic pressure varied significantly among the 10 male college students during both mild and strenuous exercise, while the systolic varied significantly (0.05) only during mild exercise. No significant variation among subjects was found for pulse pressure.

Geldreich [1953] reports that relative blood pressure increased significantly during a color naming task. When students were merely tapping keys randomly or were looking at colors without responding to them, relative blood pressure decreased significantly.

9. Blood Constituent Analysis

Astrand and Saltin [1961] found that the peak value of lactic acid was usually obtained some minutes after the end of exercise on a bicycle ergometer. The maximum values varied only slightly with the duration of the exercise, with the higher values obtaining for the higher work loads. Use of the peak value of blood lactates was suggested for determining whether a subject stopped work owing to true physiological limitations or to mere unwillingness to push himself to exhaustion. A lactic acid value above 100 mg per 100 ml of blood appeared to be a satisfactory indicator of fatigue.

Lactic acid averaged 4 to 8 mg in 20 seamen before they undertook a 1-min step test, 16-30 mg immediately afterwards, and back to normal 30 min after the test [Schwab and Brazier, 1958]. Hanging from a bar for as long as possible (generally 40-80 s) produced levels nearly identical to those resulting from the step test. When corrected for the duration of hanging, psychiatric patients (40-50 s) had slightly higher lactate levels than did normals, and myasthenic patients (averaging 30-40 s on the bar) had much lower levels. In this series of tests, lactic acid levels differentiated the subjects better than electromyograms, which showed no differences between controls and psychiatric patients, and did not change significantly during the hanging.

The level of eosinophils—a particular type of white corpuscle whose numbers are sensitive to bodily stresses—has been suggested as a promising indicator of fatigue. There appears to be a linear relationship between the eosinophil count and both the effect of exercise on pulse rate and duration of exercise at a constant pulse rate. In addition to physical exercise, however, the sources of measured wide variations in eosinophil counts include individual variations in the general level; a general diurnal pattern with marked individual variations from this pattern, day to day variations in the general level, emotional stresses, dietary factors, allergies, counting errors, and unassignable causes accounting for about 3 percent of the total variance [Redfearn et al., 1957]. Swanson [1952] examined the diurnal variation of eosinophil cells to determine the optimal schedule for detecting eosinopenia (a drop, at times to zero in the number of eosinophils). He concluded that counts must be done at the same time each day if comparisons are to be made of solitary counts. The morning was determined to be a particularly unsuitable time for measuring induced falls, as the count normally drops during the morning.

Domanski et al. [1951] took eosinophil counts before exercise on a treadmill and 1, 2, and 3 hr after exercise. The exercise was not found to be invariably associated with a negative eosinophil response. The response magnitude was different for different individuals, and was also in different directions. Unfortunately, the usual morning count fall may have compromised the results, as all control and test measurements were made in the morning. Domanski [1953] later examined eosinophil levels in F–85 fighter pilots in combat over Korea. For routine missions, eosinopenia was significantly associated with poor and very poor pilots, not the average or better pilots. After a difficult mission, absence of eosinopenia was confined to the average-or-better group, who were presumably under less emotional stress. Davis and Taylor [1954] studied the effects of infantry combat in Korea on the eosinophil count. Eosinopenia occurred after short, intensive combat, but not in a group exposed to prolonged, less intensive combat. The latter group however, did show eosinopenia 11 days after combat. The total white cell count was low in the intensive-combat group, but normal for the other. Combat produced no changes in blood volume, plasma chloride, plasma CO_2, or blood sugar levels. The eosinophil diurnal cycle in mice was found by Visscher and Halberg [1955] to be apparently related to activity levels and to the light-dark cycle as seen through the eyes.

A study of TV studio and subway control panel operators [Kikolov, 1960] revealed a rise in blood sugar level during the working day. Miller and Mason [1964] measured 17-hydroxycorticosteroids (17-OH-CS) levels in both blood and urine of rhesus monkeys (macaca multata), and found that 17-OH-CS seemed to be related more to psychological stress than to the amount of work the monkeys were required to do.

10. Urinalysis

Pace et al. (nd), in a study of infantry combat in Korea, reported that urinary sodium and potassium, 17-ketosteroids (17-KS), glucose, and nitrogen levels following combat were significantly different from control levels. Glucose was still significantly high ($p<0.001$) 10 days after combat. On the other hand, chloride, urea, uric acid, creatinine, and 17-OH-CS did not differ significantly from control levels after combat. As over 80 percent of the urinary 17-KS are believed to be of adrenal cortical origin, and thus are secreted in response to perceived threat and other stresses as well as fatigue, the use of this measure as an indicator of physical fatigue or amount of work done is compromised.

Commercial jet pilots were studied by the Flying Personnel Research Committee [1965] on transatlantic flights. Patterns of urinary excretion of noradrenaline and adrenaline for a particular subject were similar for flights to different destinations, and the two secretions tended to rise and fall together in successive samples of urine. Sodium, potassium, inorganic phosphate, and nitrogen were all excreted in the normal range. Parahydroxyphenyllactic acid (PHPL) was also excreted in a degree consistent with an unexceptional work load. Kramer et al. [1966], also studied a small group of pilots during 18-hr, moderately fatiguing flights. Results included an increase in 17-OH-CS secretion, implying that stimulation of the cortex of the adrenal had taken place; and decreases in excretion of uric acid, potassium, and the amount of urine, suggesting some depression of metabolism. Tiller [1961] measured seven subjects wearing various flight suits during 6-hr simulated flights in an F9F simulator. He found no significant increase in epinephrine or norepinephrine levels while subjects wore a summer flight suit, but norepinephrine increased ($p<0.05$) while wearing a pressure suit inflated to either 0.05 or 2.0 lb per square inch pressure. Tiller concluded that this amine increase was an indicator of physical, rather than psychological, stress.

11. Saliva Analysis

Pace et al. (nd) examined saliva constituents as well as urinalysis for their subjects under combat stress. The men chewed paraffin for 10 min to stimulate the flow of saliva, and then collected 15 ml of saliva through a funnel into a vial while continuing to chew the paraffin. Specimens were centrifuged to remove solid matter, an aliquot was diluted with distilled water, and the sodium and potassium concentrations were determined by standard flame photometry. Controls showed a relatively constant potassium level between individuals, but a large individual variation in sodium. No correlations were found between salivary and urinary sodium for the control groups. Unfortunately, no saliva was collected from the group involved in short, intense combat. For the group exposed to prolonged, less intense combat, sodium concentration and the sodium/potassium ratio tended (but not significantly) to be lower than normal, both immediately after combat and 10 days later.

Sour candy was used by Shannon [1966] to elicit saliva flow of six men marching 10 miles in 2 hr on each of 5 successive days. The mean fluid flow rate before marching was not significantly different from rates immediately after or 2 hr after the hike. No significant changes either were found in concentrations or rates of secretion of 17-OH-CS, sodium, potassium, or chloride. Shannon also [1967] found that mental exercise (adding multidigit numbers) did not affect the rates of salivary flow for 225 young male military enlistees, either under unstimulated conditions or under stimulation by chewing either paraffin or sugared chewing gum.

Saliva flow was collected from pilots and non-pilots all riding in the second seat during cross-country jet fighter flights by Warren [1966]. A plastic device was molded to the individual's bite for easy positioning over the parotid (salivary) duct opening. Plastic tubing led from the collector to a rack of test tubes beside the subject, who put samples from different times into different test tubes. Subjects who had previously flown the type of plane used in the tests experienced rises of 17-OH-CS levels during preflight, take-off, and landing. These rises were considerably above their control-day mean values, as well as above the mean values of nonpilots during corresponding portions of the flights.

Plattner [1967] reports that a kneepad saliva collector is being built at NASA's Edwards Air Force Base Flight Research Center to collect samples in flight through a tube leading to a mouthpiece fitted to a saliva duct.

12. Electroencephalogram

McDonald et al. [1963] recorded 4 channels of EEG, but used only 2 (left and right occipital) to measure the state of alertness or drowsiness of subjects. The effects of 72 to 98 hours of sleep loss upon performance of psychological and psychomotor tasks was studied by Williams et al., [1958]. EEG Alpha amplitude was found to decline with increasing sleep deprivation; and errors of omission on an auditory vigilance task were associated more consistently than other responses to the decrease in Alpha.

13. Skin Resistance

Changes in the electrical resistance of the skin have been variously called the galvanic skin response trodermal response (EDR). They result from autonomic responses to stimuli, and have been used as indicators of alertness, fear, apprehension, panic, and placidity. Changes in resistance are the result of eccrine sweat gland activity, and those glands in the palms of the hands, finger tips, and the soles of the feet are the most sensitive to changes in emotional state and are the locations usually measured for skin resistance. Two electrodes are used, and can be placed either on the same palm or sole or on different ones. Skin resistance readings are affected by the size of the electrode used, the area covered with electrolyte, and changes in the environmental temperature.

Ekey and Hall [1961] recorded GSR with electrodes placed on the hands of subjects exercising, with rest intervals, on bicycle or torsion-bar ergometers. While the trends of heart rate and blood pressure response were quadratic over time, GSR increased linearly with work over time at all task levels. In addition, heart rate and blood pressure exhibited a decreasing rate of recovery with time, while GSR rest functions were monotonically increasing through all work-rest cycles.

Palmar skin conductance was used by Geldreich [1953] as a measure of light homogenous mental work (pressing the proper key when any one of four different colors were presented). Skin conductance was greater during the performance of this task than while resting, watching colors, or tapping keys randomly. The level of palmar skin conductance maintained during the different forms of work was related to task difficulty, degree of subject's alertness, amount of bodily tension, and the amount of energy mobilized to respond to the situation.

Glassner and Peters [1959] found physiologic responses to be inversely related to the level of difficulty of items taken from the U.S. Army General Classification Test. Skin resistance was measured with gold-plated copper electrodes and standard electrode jelly, held in place by pressure-sensitive tape on the insteps of both feet. Three values were analyzed—basal skin resistance (BSR) level in ohms measured every three seconds, BSR deviation (difference in ohms of BSR from interval to interval), and BSR change (number of changes per minute irrespective of amplitude)—and all three were inversely related to task difficulty.

Carlson [1961] used a wire cloth electrode on the sole of each foot to record GSR in his study of the relationships between a vigilance task and different temperatures and atmospheric oxygen levels. Basal skin resistance and the number of nonspecific responses were found to be directly related to temperature, but were unaffected by a lowered oxygen content of the air. Blood flow and performance measures were also unrelated to oxygen content.

Independent studies conducted by Johnson and Corah [1963] revealed differences in skin resistance between Caucasian and Negro Americans. In a study of children in a resting state, zinc electrodes were attached with zinc sulfate jelly to the first and third fingers of the right hand. Mean Negro skin resistance was 40,000 Ω above that of the Caucasians, a difference significant beyond 0.001. Palm-to-palm recordings were used in a study of adults, and a doorbell buzzer sounded at intervals to stimulate autonomic reactivity. Mean adult Negro resistance was 373,000 Ω and that of whites was 171,000, also significant beyond 0.001. No significant differences were found in spontaneous GSR activity.

14. Electromyogram

Electromyography (EMG) records the minute electrical current given off by muscle fibers as they are activated. Measuring the amplitude of the EMG gives an indication of the muscle tension. Electrodes are positioned on the surface of the skin over the muscle in question. As with skin resistance, there are many factors which influence the production of the EMG potential. These include [Davis 1959:4, referenced in VI A of this report]: the type of muscle tissue (smooth or striated), use of the muscle (postural or otherwise), size of muscle (normal, atrophic, or hypertrophic), sex of individual, degree of individual development, degree of fatigue present, number of muscle fibers per bundle (per nerve fiber or motor unit), number of muscle bundles involved, oxygenation, metabolism, and blood flow.

Travis et al. [1951] studied the effects of different illumination levels (220 to 0.2 fc) on reading fatigue in a few people. Muscle action potentials (MAP) were taken from muscles just above the eyebrows by electrodes placed two inches apart in a headband, and recorded on tape. Some subjects showed an increase in MAP at low levels of illumination. A marked increase in MAP occurred when the book being read was set at twice the subject's normal viewing distance. In another study of visual tasks, Ryan [1953] reported no significant differences in MAP with illumination varied between 5 and 50 fc. In part of the study, a strong glare was introduced in the second or third 10-minute section of a 30-min test. All of the significant effects of the glare occurred in those subjects who worked under glare during the second period. Although those who worked under glare for the third period produced their highest MAP at this time, the control (no glare) group did also, with very little difference between these groups.

Lundervold [1957] conducted a series of studies into one-key tapping on a typewriter. Experienced typists working at their own pace for a long period produced a constant oscillation of MAP. When they were required to speed up, however, both the amplitude and rate of MAP increased in both muscles directly involved in the tapping task and in those not directly involved. When the typists reached a state of fatigue they slowed down, but the MAP continued to increase. Results were similar for subjects who had not used a typewriter before, except that their muscles contracted more forcibly and for a longer time. Under conditions of cool room temperature, loud noise, or bad lighting, muscles contracted more vigorously, and more muscles were used. Pulse rate, respiration rate, and sweat gland activity varied in the same manner as the electromyographic measures.

Benson and Dearnaley [1959a] asked subjects to try to keep a constant 10-kg pull on an isometric strain gage for as long as they could. MAP were taken from the gastrocnemius soleus muscle group — a group not directly involved in the pulling. The rate of increase of MAP with time was greatest under competitive conditions and least when no competition was involved and there was no display of errors (deviations from the 10-kg pull) to the subject. There were appreciable differences in the pattern of increasing EMG activity between subjects. In a second experiment, Benson and Dearnaley [1959b] required their subjects to make three pulls on the strain gage, 5 min apart. The increase in EMG activity during a particular pull was more rapid for the second and third pulls than for the first.

Weight-lifting by flexing one finger was analyzed by Klein [1961] by electromyographic recordings from the working forearm. Faster work rates were associated with significantly higher MAP. Muscle Action Potentials were also higher following exposure of the hand to cold than to warm.

Knowlton [1951] studied one-handed repeated lifting of various weights to the point of subjective fatigue. Electrodes were placed at each end of the muscle involved, the biceps brachialis. Initial MAP voltage varied directly with the weight. MAP amplitude was greater at the onset of subjective fatigue than during the initial contractions. In poliomyelitis patients with muscles of grades G+ and F+, MAP voltage decreased during repetitive contractions.

Schwab and Brazier [1958] report that electromyograms were nearly identical for normal subjects and psychiatric patients during the hanging-bar test.

15. Perspiration

Perspiration has most often been measured by weighing the subject before and after he engages in an activity, and computing the change in body weight, corrected for any fluid intake or elimination. Not all of the sweat which the body produces is always evaporated, as some may be absorbed by clothing. The ability of the atmosphere to absorb water vapor decreases as humidity increases, and a humid atmosphere may not be able to evaporate perspiration as rapidly as it is produced. For these reasons, two body weight measurements are often made before and after exercise. Total sweat production is calculated from initial and final weights made when the subject is nude and has wiped off all perspiration from the skin, and sweat evaporation is taken to be the difference between initial and final weights while the subject is wearing clothing.

Winsmann et al. [1953] calculated sweat production from the changes in nude body weight which occurred while men walked on a treadmill while carrying a backpack and sometimes wearing an armored vest. Sweat loss was significantly greater ($p < 0.01$) when the subjects wore the vest, and metabolic rate was also elevated ($p = 0.001$. Final pulse rates, however, were not significantly different.

Although significant differences were found [Baker, 1958a] between post-exercise rectal temperatures of matched pairs of American Negro and White soldiers walking in mild hot-humid conditions, sweat loss was the same for both groups. When two other groups were compared under hot-dry conditions, no differences in sweat production or evaporation were found either, although there were differences in both pre- and post-exercise rectal temperatures. Pulse rates were also the same for both groups in both conditions. Hanson [1961] also obtained no significant differences in sweat production and evaporation between paired Negroes and Whites when fully clothed under hot-dry desert conditions. Sweat production increased significantly when subjects were exposed clothed to the sun and also when they exercised while wearing an armored vest.

Randall et al. [1953] describe a method of measuring evaporative water loss by a desiccating capsule. An aluminum capsule with an aperture area of 8.54 cm^2 is charged with 5 to 7 g of activated alumina desiccant which is held in place by a thin blotter disk 5 to 7 mm inwards from the capsule rim. Although the ability of the desiccant to absorb water is curvilinear over time, deviations from strict linearity over the range of general usage to measure sweat evaporation (10 to 20 min) are very small. The capsule will, however, fail to absorb all the water vaporized at rates above 0.30 to 0.50 mg per square centimeter of skin area per minute, and it is therefore necessary to mop excess moisture from the sampled skin area with a previously tared blotter when the capsule is used to measure high sweating rates.

Adams et al. [1963] measured body evaporative water loss by passing a stream of air through a plastic capsule placed over the skin. As the air absorbs perspiration its density increases, causing a change in its thermal conductivity which can be measured electrically by a thermal conductivity cell. This device can measure the instantaneous rate of sweating, temporal changes in the rate, and the total amount of water produced during a given time period. This method was used by Hauty and Adams [1965b] to measure changes in the circadian rhythm of palmar evaporative water loss caused by abrupt transport from Oklahoma to the Philippines. The plastic capsule was sealed to the center of the subject's left palm and sampled a 1 cm^2 area five times a day 25 min each time. Water loss rhythm required eight days to shift to Manila time from Oklahoma time—twice as long as that taken by rectal temperature and heart rate to adapt.

16. Body Weight Change

Brouha and Maxfield [1962] compared the body weight responses of two subjects pedaling a bicycle ergometer in comfortable atmospheric conditions (72° F. dry bulb, 50% relative humidity) and in warm-humid surroundings (91° F., 97% RH). The mean body weight loss was 250 grams in the comfortable environment and 600 g in the warm one. Oral temperature and heart rate also differed under the two conditions, while oxygen consumption did not.

In the study by Kreider et al. [1961], of load transport on the Greenland icecap, half of the subjects were on full rations and half on 60 percent rations. The mean body weight of the subjects on full rations fell 1.6 kg during the first 10-day trek and 1.8 kg during the second, while those on the reduced ration lost 2.7 kg and 3.8 kg. In another study [Shannon, 1966], the mean body weight of subjects who went on a 10-mile, 2-hr hike every day for five successive days decreased from 173.4 lb. to 170.7 lb. during the period ($p < 0.01$).

17. Body Temperature Response

Brouha [1960c] took the oral temperature of subjects before and after they exercised on a bicycle ergometer in cool, normal, warm-humid, or warm-dry conditions. In cool (60° F.) surroundings the body tended to cool off during exercise, while in a 72° F. environment, body temperature changes during exercise periods and the final recovery period were insignificant. The oral temperature increased in the warm environments and rose the same amount in surroundings of 90° F. and 81 percent RH as in 100° F., 50 percent RH conditions, but recovery was faster in the warm-dry condition than in the warm-humid.

Christensen [1953] reports that the internal body temperature of workers performing certain operations in an iron foundry exceeded 102° F.

Baker [1958a] monitored body core temperatures of his Negro and White subjects with rectal catheters containing thermocouples during the experiment in the warm-humid environment, and with a clinical thermometer in the hot-dry test. The Negro body temperature was significantly lower than that of the Whites in the warm-humid conditions and significantly higher when walking nude in the sun in the hot-dry.

Hanson [1961] found no significant difference between Negroes and Whites in rectal temperature during a study of the effects of exercising and wearing an armored vest in hot-dry conditions. Body temperatures increased significantly when subjects walked in the sun and when they wore body armor.

Hauty and Adams [1965a, b] measured rectal temperature with a thermistor probe with readings recorded every 30 minutes in their studies of circadian rhythm shifts as a result of rapid transport between Oklahoma and Tokyo [1965a] and between Oklahoma and Manila [1965b]. Mean rectal temperatures took three to five days to adjust to local time after the flight to Tokyo, and one day to shift back upon return to Oklahoma, though there were large interindividual differences. After the flight from Oklahoma to Manila, body temperature shifted in approximately four days, and it took one to two days to shift back after the return to Oklahoma.

B. Psychophysical Measures

1. Flicker Fusion Frequency

The flicker fusion frequency [FFF] or critical flicker frequency [CFF], is the minimum frequency, in terms of the number of flashes per second, at which an intermittent light appears to the observer to be shining continuously. The critical frequency may be determined by increasing the rate of a slowly flashing light until it appears to be steady, and by decreasing the rate of an apparently steady intermittent light until the observer perceives it to be discontinuous. The FFF appears to be an index of the excitability of the central nervous system, and the critical frequency drops in response to some stresses, such as anoxia, acidosis, metabolism disturbances, and work.

Br(-ek and Simonson [1952] found no significant differences in FFF, eye movement rate change, or subjective discomfort score between subjects looking at small letters illuminated by 5, 100, or 300 fc. Measures which did differentiate the three ilumination levels, however, were performance, performance decrement, and eye blink rate.

Ryan et al. [1953] found also that prolonged reading under various illumination levels and degrees of glare was not associated with significant changes in FFF. When subjects spent 3 hr in a warm-humid environment and also underwent the mental stress of an unannounced civics test [Ward et al. 1965], their FFF decreased very significantly ($p < 0.01$). The mental stress alone was associated with a less significant decrease in FFF ($p < 0.05$).

Wendt [1953] examined motivation, boredom, and performance on arithmetic tasks with high school and college students. The CFF dropped more for the less motivated subjects than for the highly motivated ones, and did not appear to be necessarily related to subjective ratings of fatigue. Whittenburg (nd) tested 13 male college students on the Mackworth Clock Test for 3 hr under each of two conditions: (a) responding only to the occasional double jumps of the pointer, and (b) responding to both the standard single jumps and the double jumps. Large individual differences in errors of omission precluded any trend concerning perceptual efficiency as a function of time on the task. CFF was measured with the Krasno-Ivy Flicker Photometer—an episcotester, with alternating ascending and descending trials. Significant ($p < 0.05$) decrease was found for (a), but not in (b). Under condition (b) only, there was a significant relationship between CFF, errors of omission, and a 34-item multiple-choice stress e..erience inventory.

When Laporte [1966] compared gymnastic and passive rest pauses for post office workers, he found the CFF to be significantly better ($p < 0.001$) after the gymnastic work break than following the standard rest. Fischer et al. [1961] had 25 female telephone operators on various shifts make 15 FFF determinations during the last 10 min of each hour of work. Subjects who reported subjective fatigue also tended to have depressed FFF scores, but there were large individual differences in general. An increase in FFF was noted for all subjects after a 30-min rest period. A long-term on-the-job analysis was conducted by Grandjean [1959] on 13 to 15 female telephone operators. FFF was generally decreased significantly at the end of a shift.

Hauty and Adams [1965a and b] measured FFF on subjects following long distance east-west jet flights, and found no significant changes. Three-man antisubmarine warfare helicopter crews were studied by Davenport [1965] during three, 2 ½-hr flights and three, 1-hr test periods daily for 5 days. Although FFF did not change significantly throughout the day for the subjects, differences significant beyond 0.05 were obtained between subjects and a control group for the test period as a whole.

2. Eye Blink Rate

The rate at which the eyelid blinks appears to be correlated with the general somatic tension level of the body, and varies consistently from individual to individual and from task to task. Eyeblinks can usually be counted by an observer about as accurately as by a recording device. In the study by Brozek and Simonson [1952] of six subjects reading letters briefly exposed at three levels of illumination, the average blink rate differed significantly between illumination intensities, while FFF, discomfort score, and rate of eye movements did not.

3. Pupil Diameter Change

Hess and Polt [1960] were concerned with: (a) devising the best method for recording dilation, and (b) determining effect of emotionally toned or interesting visual stimuli on pupil size. The method chosen was photographing the eye with 16 mm movie camera, projecting the film with a Percepto Scope, and measuring the pupil diameter on the projected image. Change in pupil size was positively associated with the degree of interest or emotion in what was viewed ($p < 0.01$) Hess and Polt [1964] also studied five subjects mentally solving simple multiplication problems. Pupil measurements were made as above, and pupil size increased up to the point of problem solution and then decreased to normal size.

Kahneman et al. [1967] photographed nine student's pupils on infrared film by infrared strobe light. Subjects heard a string of 4 digits presented by a tape recorder at the rate of 1 per second, paused a second, and then responded once a second by adding 1 to each digit heard. Subjects simultaneously monitored a screen flashing 5 letters per second, looking for the letter "K". Average pupillary response curve on correct trials showed a steady dilation (from 5.3 to 5.7mm) through the listening phase and the first part of the response phase, then a decrease in size. Rate of constriction of the pupil during the final 2 s of the task appeared to depend on the level of illumination to which the eye was exposed. Lowenstein et al. [1963]. Subjects in darkness fixated on a red spot, and their pupils were recorded by an infrared-sensitive electronic pupillograph. It appeared that, for alert subjects, pupils are large and quiet in darkness (for periods of up to several hours), but when the subject is tired, pupils oscillate in diameter.

4. Coordination

In Davenport's [1955] helicopter crew study, he employed a speed and coordination test consisting of a charged stylus used with a sectioned disk rotating above a plate into which a number of holes were cut at random. Subjects tried to stick the stylus into the holes as many times as possible during a 2-min run. A tapping-rate test with a metal stylus and plate was also used. No significant decrement was found for either test as a function of the prolonged series of flights.

Hussman [1952] set up a tapping test to diminish the learning factor as much as possible by using a very short test period and by having each subject use his nondominant arm. The test employed was the Dunlap modification of the Whipple Tapping Board, which had two, 3-in wide metal plates to be tapped alternately with a metal stylus. It was assumed that requiring subjects to box with an opponent in the ring would be associated with different levels of fatigue and anxiety than merely punching a bag. The tapping test, however, was not a reliable measure of the differences between these two physically related activities.

McGehee et al. [1953] used a dual pursuit test, with a stick-controlled dial 3 in to the right of a rudder-controlled dial. Response measures were the total time on target for the two pointers both separately and simultaneously. During 13 hr confinement in an F–84 cockpit, performance improved over pretest levels for subjects on dexedrine, and decreased for subjects with a placebo and with no pill. Performance on an addition test, and on a discrimination reaction time test were better with dexedrine than not. but the pursuit test was the only one to show improvement over pretest levels. The improvement may have been due to learning still occurring.

Three studies by Payne and Hauty [1953, 1955, and 1957] report on the effects of various drugs, motivational levels, and work-rest ratios upon performance of the USAF School of Aviation Medicine Multidimensional Pursuit Test. This test simulates aircraft instruments and controls with a panel containing four instruments. the pointers of which can be made to drift eccentrically and unrelatedly about their respective nulls. The subject corrects the instruments by manipulating aircraft-type controls. Dexedrine postponed or minimized work decrement, while a sedative (benadryl-hyoscine) hastened and enhanced it. An indication was given that there may be an inverse relationship between motivation level and performance decrement. Decremental rate varied inversely with the length of the intertrial interval, when rest periods were interpolated between practice periods. No conclusion concerning an optimal work-rest ratio was reached.

Pearson [1957], in a study of 100 volunteer basic airmen, found that feelings of fatigue, as indicated on a 13-item Feeling-Tone Checklist, had no significant relationship with performance level over 3 hr on the USAF SAM Multidimensional Pursuit Test.

5. Steadiness

In Hussman's [1952] comparative study of bag-punching versus boxing with an opponent, he concluded that steadiness was the most promising behavior-decrement indicator for assessing fatigue effects ($p < 0.001$).

The subject was required to hold a needle 0.020 in. in diameter at arm's length for 20 s in a 0.136 in. diameter hole. In a blind steadiness test, the subject closed his eyes and held the same needle in a larger (0.358″) hole, and this test differentiated the two activities at the 0.05 level of significance. As noted above, a tapping test was found to be unreliable as a measure of this activity, and flicker fusion changes were too small to be useful in prediction. The only significant correlations found were between the steadiness and blind steadiness tests ($p < 0.05$).

Vetter and Horvath [1961] measured tremor in four subjects before, during, and after work on a bicycle ergometer to exhaustion (180 heartbeats per minute). Within the first few seconds of starting the exercise there was a marked increase in tremor amplitude and a decrease in tremor frequency. Recovery following exercise was accompanied by a rapid initial return toward control values. By 7 min after exercise, tremor amplitude and frequency were practically at control (prework) levels, although heart rate was still elevated.

6. Reaction Time

Aiken [1957] used a self-paced discrimination optical reaction time test in which a target light produced one of four colors at a time and the subject responded by pressing the appropriate one of four telegraph keys. The investigator compared massed with distributed trials, and measured latency of correct response, errors, and psychological blocks. Blocking behavior was found to be independent of either errors or response speed. but was correlated with latency.

Grandjean [1959] tested 14 female telephone operators before and after their work shift, and found that optical reaction time increased significantly at the end of the shift for 13 of the subjects.

The effects of disruption of the diurnal activity pattern were studied by Hauty and Adams [1965a] through transporting a group of subjects by jet plane from Oklahoma City to Tokyo, testing for a few days, and then returning to Oklahoma. Several reaction time tests were used, involving a manual response to (a) a single auditory stimulus, (b) one of several possible visual stimuli, and (c) a single visual stimulus. Decision time was computed by subtracting the mean time of reacting to the single visual stimulus from the time required to react correctly to one of several possible visual stimuli. After the flight to Tokyo, mean reaction time was increased and did not return to the preflight level until three days later. Following the return flight to Oklahoma City, reaction times returned to normal after two days.

A second experiment [Hauty and Adams 1965b] involved flights from Oklahoma City to Manila and return. Various stimulus-response conditions were measured by a Lafayette Multi-Choice Reaction Timer. Reaction time and decision time were both significantly slower during the first day in Manila, but had returned to normal by the second. Both were also slower than normal on the first day of return to Oklahoma, but were not so slow as they had been in Manila.

Ruff et al. [1966] studied the effects of transatlantic flights upon 75 German air crew members. Mean optical reaction time increased for subjects when compared with controls over a comparable period of time. Reaction time increased 120 percent above that of controls during a Frankfurt—New York City flight. Following a 24-hr rest in New York, reaction time was reduced to only 60 percent above that of the control group; but at the end of the return flight, it was 200 percent greater.

A decrement in discriminative reaction time following 10 to 14 hr of confinement in an F–84 fighter cockpit was found by McGehee et al. [1953]. Administration of dexedrine was not associated with any improvement in performance. The test used required the subject to flip one of four switches, according to the relative positions of red and green lights.

Patel and Grant [1964] used the Multiple Serial Discrimeter to compare reaction time performance of 120 male and 120 female students. Trials required a subject to match one of four lights to its proper key. Twenty trials, each requiring 16 responses, were followed by a 10-min rest and then by five more trials. Women were found to show greater average recovery from prerest decrements than were the male subjects.

Pierson [1963] used 26 male medical students in a test of reaction time and movement time in response to a visual stimulus preceded by an audible preparatory signal. The subject responded to the stimulus by releasing a microswitch (which stopped a timer that measured reaction time and started a second timer) and moved his hand forward 11 in to interrupt a photoelectric beam (which stopped the second timer and recorded the time to make the movement). Trials continued for as long as the subject was able to go on. There was a significant relationship between subjective fatigue (the point at which the subject stated that he believed he was slowing down) and reaction time, but not with movement time. Although seven subjects indicated boredom at some point during their performance, boredom did not correlate significantly with either the onset of subjective fatigue or endurance.

A group of 15 female students later [Pierson and Lockhart, 1964] took the same test. For these subjects, the onset of subjective fatigue was significantly related to isotonic endurance and to both reaction itme and movement time scores under fatigued conditions. Although the normal (unfatigued) reaction time scores of the female subjects were not significantly different from those of the males, the females' normal movement time scores were significantly slower. Men could perform the repetitive task for a longer period than the women could, but there was no significant difference in their subjective opinions as to when their performances were slowing down.

In his experiment with the Mackworth Clock Test, Whittenburg [1953] found that during the second hour of the 2-hr test female college students made significantly fewer errors of omission than male students did.

Kennedy and Travis (1947) measured reaction time to a simultaneous buzzer and light flash in a monotonous situation. Muscle action electrical potentials were recorded from supraorbital and hand muscles during the experiment, and it was found that, as reaction time increased, muscle action potentials decreased in frequency.

C. Psychological Variables

1. Mental Performance as an Indicator of Fatigue

Adams and Chiles [1961] confined two B–52 crews for 15 days in small crew compartments on a 4-hr on, 2-hr off duty cycle. Arithmetic computation, probability monitoring, and auditory vigilance trended towards decrement, while pattern discrimination improved. GSR, heart rate, and respiration rate decreased.

Baker and Ware [1966] studied 40 Army trainees working 2 hr on each of 2 days doing 4 routine and montonous tasks. Performance on a vigilance task could not be predicted by performance on the other 3 tasks—sorting, simple assembly, and an addition task of 2-digit numbers. There were, however, significant coefficients of concordance (Kendall's W) between the last 3 tasks.

Botwinick and Shock [1952] gave 50 people aged 20 to 29 years, and 50 people aged 60 to 69 years 6 speed tasks, in order of administration: (a) writing digits, (b) writing words, adding (c) 3-digit, (d) 6-digit, and (e) 9-digit problems, and (f) substituting digits in the subtest of the Babcock-Levy Scale. Decrement in performance rate was found for all tasks except for speed of writing digits, which had an increasing rate. Each task apparently took about 2 min to complete. Larger decrements were made by the younger subjects, but both the initial and final performance levels in every task were greater in the younger group. Neither the sex nor the education level of the subjects made any significant differences in the results.

Drew [1960] tested 140 pilots in a grounded Spitfire cockpit with 2 hr of simulated maneuvers, level flying, maneuvers, and landing. The pilots had to monitor instruments and work out a schedule of maneuvers from a set of instructions. All of the pilots reported subjective mental fatigue at the end of 2 hr, and their performance deteriorated in both accuracy and response time. Fatigued pilots tended to split a complicated task into its component parts, rather than treat the system as a whole, and this caused serious errors. Pilots tended to ignore peripheral instrumentation and warning lights as they became fatigued. Increase of "careless errors" occurred as subjects became fatigued. Timing of maneuvers, rather than accuracy, decreased with fatigue.

Forty women office clerks compared passive and gymnastic 10-min rest pauses in the middle of the afternoon [Laporte, 1966]. They were given these tests immediately before and after the pause: CFF, Wechsler's digit-symbol test, hand dynamometer, Pieron's dynamic tremor test. The gymnastic group was better than the controls on all four tests, with a highly significant difference on CFF and digit-symbol test.

Lybrand [1952] induced fatigue by various combinations of marching 5 miles wearing a 40-lb pack, and sleep loss for one night. Performance on the Kohs Block Design, Perception of Hidden Figures and the (Müller-Lyer Illusion was used as measures of fatigue. Marching produced more efficient performance of the Kohs Block Designs, while sleep loss produced less efficient performance on the Perception of Hidden Figures and the Kohs tests. Performance on the tests was more efficient after mild physical activity and less efficient after sleep deprivation.

Williams et al [1958] studied people who had gone 72 to 98 hr without sleep. Subject-paced tasks (graded on speed)—reaction time, task durations, adding numbers, communications, and concept-attainment—and experimenter-paced tasks (graded on accuracy)—vigilance, tasks with more complex responses and information-learning tasks—were given. Speed was found to decrease with sleep loss, as a result of primarily an increase in frequency and duration of lapses. Errors were affected mostly by the length of time during which a task continues without interruption and without a change in the stimulus-response conditions.

2. Subjective Fatigue

Twenty pilots pulling a 2-handed dynamometer were asked at 15-s intervals how much longer they could maintain the 10-kg pull [Benson and Dearnaley, 1959b]. Intercorrelations of EMG recordings, estimates of endurance, and other psychological data were not significant. Subjects were asked after the test why they gave up and what feelings they had.

Chiles et al. [1960] conducted three experiments into human performance during various levels of ionization. One involved small-group participation in discussion and cooperation in accomplishing a few tasks. Subjects evaluated their own feelings with an adjective check list and also gave their impressions of the attitudes of other subjects. Only 5 out of 100 *F*-ratios were significant beyond 0.05 and, therefore, the authors concluded that the various ion concentrations did not seem to affect the attitudes of subjects working as groups. Also, the ion levels did not affect performance on either the Mackworth 3 clock test or on a matching task.

Collins and Pruen [1962] found that most subjects remarked of a feeling of slight tiredness after a 2-hr period of setting a vernier gage, with more complaints when working at an illumination level of 1 lm/ft^2 than at 30 lm/ft^2. There was, however, no clear relationship between subjective feeling and objective score. Colquhoun [1959] gave subjects an hour long simple inspection task. One group was told they would be given a break halfway, and were in fact given a 5-min rest after 30 min work, and the other group worked the full hour without a break. Subjective fatigue and boredom were more prevalent in the group without rest than in the rested group.

Davenport [1955] measured and interviewed 12 men in an Anti-submarine Warfare helicopter unit before, during, and after flights. Pilots and sonar men felt the nature of the flights had not interferred with their performance, although they were fatigued after the flight. This was supported by safety pilots, acting as observers, who reported noticing symptoms of fatigue, but no decrements in pilot performance. A controlled interview indicated that the principal things affecting fatigue for the sonar crew were psychological factors such as monotony, boredom, anxiety, and frustrations.

In Drew's study [1960] of 140 pilots in a grounded Spitfire cockpit, all pilots reported subjective mental fatigue at the end of 2 hr. Irritability increased with fatigue, and the subjects had an awareness of physical discomfort.

Fischer et al. [1961] tested 25 female telephone operators on critical flicker frequency. They found that those subjects who reported subjective fatigue on the job also had depressed CFF scores.

Griffith et al. [1950] gave 379 manual workers, foremen, and male and female office workers a Kerr "tear ballot" each half hour of an 8-hr working day. Curves of work feeling during the day for all three groups were highly similar, and it appeared that the extent of subjective tiredness was in part a function of the degree of manual effort involved in the jobs performed. Maximum subjective fatigue was evident in the fourth and eighth hours, and maximum restfulness was reported in the second and sixth hours of work.

Hanes and Flippo [1963] studied anxiety in students filling a modified Barnes pegboard. Highly anxious subjects (defined as being in the upper 3 deciles of the IPAT Self Analysis Form) reported feelings of fatigue on the task long before the low anxiety group (lowest 3 deciles). The low-anxiety group was able to work longer at the task.

During jet flights from Oklahoma City to Manila and return [Hauty and Adams, 1965b], subjective fatigue (measured by checklists with the scale-discrimination method), reaction time, and decision time were all changed on the first day in Manila, but were normal on the second day. This was in contrast to rectal temperature and heart rate, which required 4 days to shift to Manila time, and palmar water loss, which took almost 8 days.

Hueting and Sarphati [1966] studied the subjective fatigue of subjects exercising on a bicycle ergometer with workload increasing without the subjects' knowledge from 3 W to between 70 and 130 W. During the post-exercise recovery period, the subjects filled out a number of different subjective reports. It was found that subjects could best estimate their fatigue by direct rating methods rather than by comparing it with such measures as white noise intensity. A correlation significant beyond 0.01 was obtained between subjects' feelings of general physical fatigue and slope of the workload. Factor analysis indicated that during exercise there was an increase of tiredness and a decrease of physical fitness; during recovery this was reversed.

Jhurkov and Zaharianz [1960] observed subjects lifting weights to exhaustion by bending the elbow. At the point at which subjective fatigue set in, there were also found changes in the character of respiration, a reddening of the skin, and irradiation of excitation on some of the other muscles. The work level could, however, be maintained for a long time after this point, due perhaps to motivation.

Kreider et al. [1961] reported on treks on the Greenland icecape at 7,000′ altitude. Spearman's Correlation was high between the Harvard Step Test and the investigator's evaluation of subjects' endurance, and also between investigator's evaluation of endurance and subject's evaluation of ability to survive on the ice. Subjects' evaluations and a treadmill test did not correlate highly with the Harvard Step Test.

Pearson [1957] found that feelings of fatigue, as expressed on a Feeling-Tone Checklist, had no significant correlation with performance on the USAF SAM Multidimensional Pursuit Test for 3 hr.

Pierson [1963] tested 26 male medical students on reaction time (RT) and movement time (MT) to the limit of endurance. Subjects were also asked to indicate when they felt their performance was becoming slower. There was a significant relationship for the occurrence of fatigue and RT performance, but not for MT performance. Kendall rank correlation indicated no significant relationship for boredom and fatigue or endurance. Pierson concluded that fatigue, endurance, and work decrement are independent variables. Fifteen female students were also tested on RT and MT [Pierson and Lockhart, 1964]. Analysis of variance indicated no significant difference for MT under normal, fatigued, decrement (5 slowest trials), or terminal conditions (last 5 trials). The occurrence of fatigue was significantly related to isotonic endurance and to both RT and MT scores under fatigued conditions.

Ricci et al. [1965] ran college athletes on a treadmill at a rate of 10 km/hr on a 10 percent upgrade, for 3 min. Recovery (for 10 min) while standing still was compared with walking at 4 km/hr on a level grade. Both seemed to be equally effective from the physiological measures taken—ventilation volume, CO_2 output, heart rate, blood pressure, and rectal temperature. Remarks from the subjects, though not solicited, were volunteered and were recorded. These indicated a preference for the walk recovery. Subjects reported experiencing "tired" and "tight" legs while in stand recovery, but not in walk recovery.

3. Comfort and Discomfort

The effects of 24 hr confinement in an F–84 fighter cockpit were compared for subjects who were given and who were not given dexedrine [McGehee et al., 1953]. All 16 subjects were vehement and quite verbose about the physical discomfort produced by the confinement. Dexedrine appeared to remove, or permit the subject to ignore, his feelings of fatigue; resulting in an increase in motivation to perform.

Vincent [1965] had four men test a new azimuth alinement procedure for a Minuteman missile system, using a theodolite with an eyepiece only 32 in. above the floor, requiring the operator to assume an awkward position. Although all operators were reported to have complained loudly of discomfort using the new system and evidenced physical strain by constant shifting of position and facial contortions (illustrated by photographs in the report), acceptable accuracy of settings was obtained. The author cautioned, however, that long-term morale may be adversely affected by the new method.

4. Monotony and Boredom

Pierson [1963] te· ·d 26 male students for reaction time and movement time. The subjects were asked to indicate when they became bored and when they felt they were slowing down. Seven subjects expressed boredom, and a Kendall Rank Correlation indicated no significant relationship for boredom and fatigue or endurance.

D. Sociological Factors

Four SAGE Direction Center crews, involving 194 employees, were given a questionnaire about various human factors aspects of their jobs [Green, 1960]. Sixty-five percent reported that little or no tension or conflict existed among the people with whom they worked regularly. Analysis indicated that the employees in the functional activities of the Center in which more fatigue and tension were expressed also indicated: (1) less successful adjustment to operational pressure, (2) less cohesiveness, (3) less satisfaction with information channels, and (4) less favorable reaction to the supervisory structure ($p < 0.05$). The author believed the group cohesiveness factor to be the most efficient single predictor of all the other factors studied.

Shepherd and Walker [1957] analyzed attendance records of workmen in an engineering firm and two iron and steel works. Men in the 35 to 44 year age group had a slightly lower absence rate than either younger or older workers. The increase in absence among the older men was more marked for total lost time than for the number of absences. A small and irregular decrease in absence rates was noted for employees judged to work at jobs requiring increasing exposure to heat. There appeared to be no consistent relation between absence and whether work was continuous or involved some or many pauses, but both the amount and incidence of absence increased as heaviness of work increased. The presence of dust or fumes in the environment did not appear to have a consistent effect on absences.

V. Summary and Recommendations

A. Research Which Has Been Conducted

Many different approaches have been used in the study of human physical effort. Analysis of workers on-the-job has progressed far beyond the fairly primitive time-and-motion studies of the Gilbreths to include the effects of physiological, biochemical, and environmental factors in the analysis of the work requirements. New equipment devised for measuring the effects of work include miniaturized self-contained instruments for collecting saliva and monitoring respiration and heart rate, of even airplane pilots in flight. The spare capability available to an automobile or truck driver which allows him to cope with sudden emergencies can be evaluated through his performance on subsidiary tasks while he is actually driving.

The conditions under which people work have been simulated, with varying degrees of success, in laboratories where variables can be controlled or accounted for; and the performance of our closest relatives, the non-human primates, has been studied in situations for which it was not feasible to use human subjects. Medical doctors have analyzed large samples of out-patients at clinics for subjective complaints and organic disorders resulting from work. Even the small amounts of energy and motion required in tasks such as typewriting or small-parts assembly have been analyzed by strain gages installed in force platforms and by recording the electrical output of muscles. Devices to collect saliva without interrupting the worker can permit the study of chemical changes formerly requiring blood sampling.

The strength and endurance necessary for a particular task, the rate of decrement in an individual's physical capacity, and the form and amount of rest required for recovery to normal homeostasis throughout the working day have all been assessed. Sedentary work has been evaluated by studying an individual's problem solving and planning behaviors and his performance at standardized motor skill and sensory adjustment tasks. Controlled laboratory conditions have permitted scientific analysis of the effects of stress situations—noise, vibration, illumination levels and glare, sudden interruptions, and time-pressure. Endurance situations involving continued vigilance, long-distance travel, monitoring or inspection, confinement, or performance of repetitive tasks have been related to performance decrement or enhancement, changes in error rates, strength and consistency of output. Physiological and performance changes have been effected by introducing nutritional changes, alcoholic beverages, and depressant or stimulant drugs.

The importance of several variables in the worker's immediate microenvironment has been emphasized, and physiological tolerances of people of different ages and from various ethnic groups have been indicated for ranges of temperature and humidity. The often-neglected factor of air movement must be considered for its influence on the effective temperature and the subjective comfort of the individual. Limits which can be tolerated in illumination, noise, vibration and atmospheric contamination are being established along with means for controlling them. It has been pointed out that the clothing which a worker wears, especially protective clothing, must be considered as a part of his environment and should be investigated for possible physical restrictions and physiological stresses.

Differences in several factors between individuals can affect both their task performance and their adjustment to the environment. Sex makes a difference in individual's physical endurance capacity and physiological response to work. Sex can also affect movement times, error rate changes, and subjective feelings of tiredness. The ability of a worker to perform at a specific task changes in various ways as he ages. Differences in education, training, experience, acclimatization, and physical conditions are all important factors to be considered when evaluating an individual's fitness for a particular task. Genetic and ethnic factors influence adaptation to various environments, and the size and shape of the body and its components. The state of health, amount of recent sleep and rest, adequacy of diet, kind and amount of leisure time activity, and family situation are all factors which affect human performance.

The effects of work have been evaluated by measuring physiological and psychological responses and task performance changes. Even work requiring small expenditures of physical energy involve changes in heart rate, respiration rate and volume, and electrical excitation of muscle fibers. Electrocardiographs have been used primarily to record heart rate, and have shown to be oftentimes too sensitive to outside interference to be useful. Caloric intake and metabolism are, of course, vitally involved in energy expenditure, but measuring these factors is laborious and expensive. Blood pressure taken during rest periods has not been found to be a sufficiently accurate indicator of the cardiac cost of the preceding work. Biochemical changes found in the blood and urine are useful indicators of hormone production of the adrenal cortex, energy consumption, and muscle output. It has recently been found that some of these changes can be monitored in the saliva, as well. Changes in the electrical resistance of the skin (GSR, etc.) have been found to be not as valid a measure of activity as have electromyographic (EMG) recordings from specific muscles, either directly or indirectly involved in performance of a task. Body heat output as a result of energy expenditure and influenced by environmental temperature and humidity can be measured by the amount of perspiration produced and by taking surface or internal temperature readings.

The effects of work, different illumination conditions, drugs, etc., upon the critical fusion frequency (CFF) response are too small and variable for CFF to be of great practical value as a fatigue measure. Eye blink rate has appeared to be more useful, and can be obtained more easily than CFF. Standard tests of coordination, steadiness, and reaction time have been developed and validated. The size of the pupil diameter can be an indicator of interest, attention, and alertness.

Attempts to quantify subjective feelings of tiredness, boredom, or comfort have resulted in attitudinal scales and feeling-tone adjectival check-lists. Performance on various mental tasks has been predicted by standardized tests of memory, judgement, reasoning, and problem-solving. Personality inventories and psychiatric analyses indicate an individual's expected ability to work as a part of a group, to make decisions and to function under confinement or endurance situations.

Measures of task performance include changes in error rates with time, and comparisons of errors of commission and omission. Rate strength, and consistency of output are important indicators of the worker's state, as is blocking, or latency, of response. Motivation affects duration and strength of continued ouput, as well as whether decrement or enhancement of performance will occur.

B. Suggestions for Further Research

Many variables are involved in human performance. New methods are constantly being devised to measure these variables and control their effects, while the traditional measures are being revised or refined in form or usefulness. Much more research needs to be done on the effects on performance of genetic and ethnic differences among individuals. Variations in both physical responses and anthropometric differences should be studied. Body size and composition data, necessary in order for equipment to be designed and constructed to fit the people expected to use it, are lacking for large segments of the population outside of colleges and military bases. Age and sex differences in learning ability, capacity, endurance, and precision are still somewhat ambiguous.

Certain of the factors found in blood and urine analysis, especially adrenal hormones and eosinophils, are subject to so many outside variables that more closely controlled experimentation must be carried out before the effect of work upon them can be ascertained. EEG recordings of brain waves and audio recording of heart sounds are too subject to both outside disturbances and movements of the human being measured to be useful in studies of phsyical effort.

Analysis of saliva, both as to flow rate and biochemical constituents, promises to supplement some blood sampling and other chemical measurements, but is as yet still in its infancy. Tests of physical endurance, such as running, step tests, and treadmill tests, have shown surprisingly low intercorrelations. Very little work has been done with direct effects of sociocultural factors upon performance.

C. Recommended Methods for Use in The Development of a Program for Measuring the Expenditure of Human Effort in Work

(1) Heart or pulse rate and the speed with which the heart rate returns to normal following work are excellent indicators of the physical cost of work, and are very easy and inexpensive to record. Heart rate is sensitive to sedentary work and to the introduction of minor stresses such as noise. Since there are large individual differences in heart rates, the individual should be his own reference point.

(2) Oxygen intake and respiratory volume, measured by a spirometer, have been found by NASA and others to be better than caloric intake, heat output, or carbon dioxide production as measures of energy expenditure.

(3) Electromyographic (EMG) recording of muscles, those both directly and indirectly involved, provides an immediate indicator of muscle use and bodily tension. The EMG can be used to compare different ways of performing a task, record the effects of some stressors, and trace deterioration of strength.

(4) Personality and sociological inventories.

(5) Quantifiable questionnaires, scales and checklists designed to measure the subject's perception of the work situation.

(6) Rate and consistency of output and types and numbers of errors, along with their changes through time.

(7) Appropriate measures of the environment; minimally including temperature, humidity, air change rate, illumination level and consistency, noise, and time of day.

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D. Tables of Energy Costs

DuBois, Eugene F., An Attempt to Classify Occupations in Ten Task Groups According to Physical Exertion or According to the Amount of Physical Exertion Demanded. Proceedings of the American Philosophical Society, 104 (1), 111, 112 (1960). (Abstract No. 58, this report).
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VII. Abstracts and Evaluations of the Literature

A. Discussion

The literature search was conducted to review the methods currently being used to assess human performance, responses to stress, and tiredness. Generally, only reports and articles which were published since 1950 were considered. The emphasis was on the design and development of methodologies and their use in experimental situations.

Studies of factors and processes which were only indirectly related to the debilitation of effort, or whose methodology was judged to be not applicable, were examined, but not abstracted. Since the major interest here is in "normal" working conditions, studies of the effects upon performance of extreme stresses were not abstracted except as they presented a novel method or procedure for measuring performance. Many incomplete, preliminary, or progress reports, and other reports which did not contain enough data to permit evaluation of the procedure or results were also not abstracted. Most general articles, reviews of previous research, and papers which did not present original research in detail were not abstracted, but are listed alphabetically by author in the Bibliography in section VI. Bibliographies of the literature on effort, performance, fatigue, and stress are also listed in section VI.

The abstracts are presented in alphabetical order by author. Subject and author indices to the abstracts are presented in section VIII.

B. The Abstracts

1

Adams, Oscar S., and Chiles, W. Dean, Human Performance as a Function of the Work-Rest Cycle, Wright-Patterson Air Force Base, Ohio, WADD T.R. 60–248, DDC AD No. 240 656 (1960).

Abstract:

The problem studied was that of developing a work-rest schedule that would maximize the proportion of time on duty and still maintain the necessary quality of performance. The performance quality of 16 males (ages 21–24) divided equally into 4 groups under four different work-rest schedules (2 hours on and 2 hours off; 4 on and 4 off; 6 on and 6 off; and 8 on and 8 off) was measured over a 96-hour period in a flight station mock-up. Five performance tests were administered during the work periods—arithmetic computation, pattern discrimination, warning lights monitoring, probability monitoring and auditory vigilance. In addition, observational measures were provided from the experimenter's logbook, and attitudinal measures were provided from a questionnaire administered at the end of the test.

Results indicated that: (a) within the 8-hour group, performance was best in the active tasks, whereas in the 2- and 4-hour groups, reasonable motivation was maintained for all tasks. (b) Although the data obtained from the experimenter's logbook and the subject questionnaire did not differentiate significantly among the groups, there were indications that the 2- and 4-hour groups appeared to have adjusted more favorably to their schedules than did the 6- and 8-hour groups.

The author stated that performance scores continued to improve throughout the 96 hours for each of the four groups; however this improvement could be attributed to the learning process. Replication should include measurements of task efficiency and endurance after the learning process has reached a plateau, signifying understanding of the problems. More age groups should also be included before generalizations can be made concerning the optimal work-rest cycles for maximum production and efficiency. This served as a good preliminary study for the Adams and Chiles study of 1961.

2

Adams, Oscar S., and Chiles, W. Dean, Human Performance as a Function of the Work-Rest Ratio During Prolonged Confinement, Wright-Patterson Air Force Base, Ohio, ASD TR 61–720, DDC AD No. 273 511 (1961).

Abstract:

Two B–52 crews were confined to a small-volume crew compartment for 15 days during which they were restricted to a 4-hours work, 2-hours rest cycle. During the work period, various human performance and psychophysiological measures were taken, including arithmetic computation, pattern discrimination, probability monitoring, warning lights monitoring and auditory vigilance; and skin resistance, skin temperature, heart rate and respiration rate. All subjects were trained in the tasks before testing began.

Results: (a) there were significant between-day effects in four of the performance tasks. Arithmetic computation, probability monitoring and auditory vigilance all reflected a trend toward decrement; while pattern discrimination improved. (b) There were significant between-day effects in three psychophysiological variables—skin resistance, heart rate, and respiration rate. In each case there was a decrease in the level of autonomic activation. (c) With a highly motivated crew, the 4-hour-on and 2-off schedule is very successful.

This is a very comprehensive study which controls for many of the variables not controlled for in the authors' 1960 study. Included in the appendix, are earlier studies using other work-rest cycles. There is sufficient statistical treatment of the subject and comprehensive discussion and summary sections. It is a good study and one that further research is needed only to determine if subjects could maintain efficiency for longer than 15 day .

3

Adams, T., Funkhouser, G., and Kendall, W., A Method for the Measurement of Physiologic Evaporative Water Loss, Oklahoma City, Federal Aviation Agency Civil Aeromedical Research Institute Aeronautical Center, DDC #603 418 (1963).

Abstract:

This paper describes a sensitive, inexpensive system for the calibration of body evaporative water loss. The technique is based upon the varying thermal conductivity due to density changes caused by fluctuations in the water vapor content of air flowing through a thermal conductivity cell. Simplified, the system consists of an air stream that is passed over a section of the skin at a rate of approximately 200 cm^3/min. As water loss through sweating occurs, water vapor is absorbed by the air; and by measuring the increased density due to the humidity in the air, calibration of the water loss is possible. The physical model consists of a thermal conductivity cell (model 9677, GOW-MAC Instrument Co., New Jersey) housed in an insulated container with a small fan and a temperature control system which maintains the unit at 50° C. Drying units consist of tubes filled with "Drierite." There are three types of information that are easily obtained with this method: (1) instantaneous rate; (2) acceleration of water vapor production; and (3) total amount of water produced for a given time period. The advantages of this system are that it is inexpensive and gives but slight discomfort, if any, to the subject.

4

Aiken, Edwin G., Response Reversal and Fatigue, Ft. Knox, Ky., Army Medical Research Laboratory, Report No. 289, DDC AD 135301 (1957).

Abstract:

Thirty-six males, divided into four groups in a 2 × 2 factorial design, were used in a study of the influence of a fatigue-inducing situation upon the acquisition of a simple psychomotor skill and upon the subsequent interference created by changing the response requirements of the task. The apparatus presented to the subject a self-paced multiple-reaction time task consisting of four identical black telegraph keys and a target light. The target light produced one of four colors at a time, and the subject was required to then press the correct key corresponding to the color, in order to see the next color in the series. Response interference was produced by changing the order of the progression. Habit A assigned one order to the association of the keys to the colors, and Habit B, another order. The subjects performed in either a massed or a distributed situation. The massed Habit A required 800 correct responses, and the distributed Habit A, 100 correct responses in each of eight trials. In Habit B there were 600 correct responses in the massed situation, and 100 correct responses in each of six trials for the distributed. Three measures were used in the analysis of the experimental variables: latency of correct responses, errors, and psychological blocks (defined as any response the latency of which was equal to or exceeded twice the median response latency for any prescribed number of responses).

It was concluded that fatigue can cause performance decrement in even a simple task, by increasing inaccuracy, decreasing speed of response, and promoting blocking behavior. Psychological blocking was discussed as a useful measure of several fatigue effects. While blocking was found to be independent of errors and of response speed, it was correlated with latency of response ($p < 0.05$). Analysis of variance and t-tests were also made.

This is a good, comprehensive report. and indicates that more research should be done on the blocking phenomenon, to include a wider variety of tasks under a wider sampling of fatigue levels.

5

Astrand, Per-Olof, and Saltin, Bengt. Oxygen uptake during the first minutes of heavy muscular exercise, J. Appl. Physiol. **16**(6), 971–976 (1961).

Abstract:

Oxygen uptake, heart rate, pulmonary ventilation, and blood lactic acid were studied in five subjects performing maximal work on a bicycle ergometer. The one female and four male subjects, ranging in age 22 to 37, were previously trained in the experimental procedure. Muscular work was performed on a bicycle ergometer with a pedal frequency of 50 rpm. After a 10-minute preliminary exercise with an oxygen uptake approximately 55 per cent of each subject's maximum, various work loads were performed by the subjects. Maximal duration of the exercise was fixed at eight minutes. When the subjects could not continue for eight minutes on very high work loads, they were asked to work to absolute exhaustion. Altogether the five subjects performed 42 experiments which brought about exhaustion after two to eight minutes. (Inspection of graphs which accompany the text, and which record data for about half the experiments, indicated a work load range in the maximal experiments of 1800 to 3000 kpm/min for the male subjects and 1200 to 1800 kpm/min for the female subject.) Heart rate was recorded continuously on an electrocardiograph. Expired air was collected in Douglas bags throughout the period of exercise and in some experiments also during early recovery, and expired air volume was measured in a balanced spirometer. Concentration of lactic acid was determined from blood drawn from a finger tip (the hand was prewarmed in water of 40 to 45° C) and was analyzed according to Barker and Summerson. The samples were timed so that the peak concentration of blood lactate could be established.

The results: Peak oxygen uptake and heart rate were practically identical in the experiments (SD 3.1% and 3 beats/min, respectively). The heavier the work and the shorter the work time, the higher became the pulmonary ventilation. There was a more rapid increase in the functions studied when the heaviest work loads were performed. The peak value of lactic acid concentration was usually obtained some minutes after the end of the work; there was only a slight variation in the maximum with the duration of exercise, with higher values obtaining for the higher work loads. It was concluded that aerobic capacity (maximal oxygen uptake) can be measured in a work test of from a few to about eight minutes in duration, severity of work determining the actual work time necessary to establish a plateau. After a ten-minute preliminary period, about two minutes of very heavy exercise was, for young, healthy, and well-trained individuals, sufficient to adjust the oxygen transporting system so that maximal oxygen uptake and heart rate were obtained. For lighter muscular exercise, the duration of work should exceed five minutes, this time being required for adaptation before "steady state" values appear. Use of the peak value of blood lactates was suggested for determining whether a subject stopped work owing to true physiological limitations or to mere unwillingness to push himself to exhaustion (a value above 100 mg/100 ml of blood would be satisfactory).

This study recorded valuable and precise physiological measurements for subjects under heavy work loads. However, the methodology and results were sometimes inadequately or ambiguously reported in the text. The sequence of work loads, the intervals between them, the number and work levels of maximal experiments performed by the subjects, and the number and work levels of experiments in which subjects could continue for more than eight minutes were omitted. The only reported statistical analysis was the computation of standard deviations for oxygen uptake and heart rate; no statistical tests for significance were performed.

6

Austin, Frank H., Gallagher, T. J., Brictson, C. A., Polis, B. D., Furry, D. E., and Lewis, C. E., Aeromedical monitoring of naval aviators during aircraft carrier combat operation, Aerospace Medicine, **38** (6), 593–596 (1967).

Abstract:

The immediate physiologic effects of a single combat flight and the cumulative effects of continual exposure to combat flying were studied by a multidisciplinary team of U.S. Navy and NASA personnel. Data were gathered from the 86th through the 108th day of line combat operations for 32 aviators based on an attack carrier. During the first 16 days inflight recordings were made of single-lead electrocardiogram, respiration, normal acceleration, and pilot's voice. Urine and blood samples were collected 30 minutes before launch and within 30 minutes after landing, and control urine samples were taken on a pilot's non-flying days, if any. Carrier landing performance at the end of a mission was evaluated by two landing signal officers and by the ship's radar, and were empirically graded against an idealized glide-slope. The pilots were also interviewed before and after the flight. Control blood and urine samples were taken from 15 of the subjects after their tour of duty, when they were flying missions whose length and profile were similar to the combat flights, except for the absence of carrier launch and landing and enemy opposition.

The phosphatidyl glycerol fraction of the blood plasma phospholipids became elevated during the combat period, as did the phosphotidic acid, while the cardiolipin level remained relatively constant. Statistical analysis of the designated phospholipid components was reported to show significant changes in the combat pilots in contrast to that previously found in other stress states and in normal controls. The pilots were observed to be in good physical condition, not physically stressed by the individual flights, and showed no significant objective emotional disturbances throughout the period monitored. Although the pilots exhibited wide variability in landing glide-path performance, no extreme performance decrements were observed, and all of the monitored landings were successful and free of accidents.

The results of other measures and analyses and the statistical analysis of the findings reported here are being published in a later report. Although based on an exploratory investigation of a small pilot sample, the results to date are encouraging and indicate that the relation between approach and landing performance and psychophysiological measures should be investigated further in longitudinal studies.

7

Auxter, David, Muscular fatigue of mentally retarded children, Training School Bulletin **63** (1), 5–10 (1966).

Abstract:

The ability to withstand the onset of muscular fatigue, as measured by grip strength, was compared among intellectually typical and mentally retarded boys differentially diagnosed as non-brain-damaged, brain-damaged, and undifferentiated. The intellectually typical subjects were 35 boys, aged 9 to 11 years, with an IQ range between 85 and 133 (mean 101.9), free from visible physical handicap, and attending schools in Massachusetts. The mentally retarded subjects were 91 boys from institutions in the northeastern U.S., between the ages of 9 and 11, and with an IQ range of 50 to 79. The criteria for ascertaining brain damage were positive agreements among neurological examinations, EEG findings, and quantified life-history material. The subject was classified as undifferentiated if there was disagreement among the criteria. Thirty-three boys were classified as non-brain-damaged, 31 as brain-damaged, and 27 could not be differentially diagnosed. Mean IQ's for the groups were 66, 63, and 62, respectively. A Smedley Adjustable Hand Dynamometer was used to obtain maximum grip strength and the decrease of an isometric muscular contraction held for 20 seconds. Three trials were made to determine the maximum grip strength prior to the fatigue test. An audible metronome timed the test, and the experimenter recorded the lowest score registered on the dynamometer scale during each of four, five-second periods.

The score for each subject was expressed in a ratio of four times the best score on grip strength divided into the sum of the lowest recorded scores at the conclusion of each scoring period. Analysis of variance for the four subject groups was significant beyond the 0.01 level. *T*-tests were also significant beyond the 0.01 level for the differences in muscular fatigue between the intellectually typical group and each of the three retarded groups. The non-brain-damaged group performed significantly better than both the undifferentiated and the brain-damaged groups ($p < 0.01$). No significant differences were found between the latter two groups, however. Correlations between grip strength and the ability to withstand muscular fatigue were 0.21 for the retarded groups combined and -0.17 for the intellectually typical group. The author suggests the possibility that mentally retarded children might lack, to a greater degree than typical children, ". . . the ability to work past the initial stages of discomfort of fatigue which prevent them from more nearly approaching their physiological limits."

This study is a very good beginning, but much more investigation needs to be done, especially into the possibility of physiological explanations for the results indicated here.

8

Ayoub, M. M., and Manuel, Robert R., A physiological investigation of performance rating for repetitive type sedentary work, The Journal of Industrial Engineering **17** (7), 366–376 (1966).

Abstract:

Ventilation rate (volume of expired pulmonary air expressed in liters per minute) was measured in two experiments with subjects of different ages and sexes at rest and performing light tasks with varying paces. Ventilation rates were measured by a respiration gasometer, and corrected to STPD. The first experiment tested the hypothesis that: "A mean level of ventilation rate of narrow variability can be developed for both males and females while at rest." Three age groups were compared: age 20 ± two years, age 30 ± two years. and age 40 ± three years. Eight male Caucasian volunteers in each of the three age groups and eight female Caucasians of one age group (age 20) served as subjects. Half of each age group was tested in the mornings and the other half in the afternoons, each subject was measured for his ventilation rate at rest on three different days, and all measurements were completed within a period of three weeks. Body surface area (BSA) was calculated from the DuBois-Meek height-weight formula, and atmospheric temperature and humidity were controled. Testing periods lasted approximately 30 minutes, during which time the subject's height and weight measurements were taken, the subject filled out a questionnaire on anthropometric and personal data, and finally, pulmonary ventilation rates were measured at intervals of two, five, five, and five minutes, with the subject sitting in a relaxed position.

Bartlett's test of homogeneity of variance indicated that, while there were significant differences between subjects within each of the four different age-sex groups, no significant difference was found between male age groups or between the sexes in the 20-year-old age groups.

The second experiment tested the hypotheses that: "An individual's ventilation rate is linearly related to the pace at which he performs a task, provided job difficulty remains constant. A mean level of ventilation rate of narrow variability can be developed for both males and females while performing specified tasks at various percentages of standard perform-

ance." The same three age groups were used as before, with 18 male and 18 female Caucasian volunteers in each group, for a total of 108 subjects. Two light, repetitive tasks were used—filling a pinboard and card dealing—at paces of 80, 100, and 110 percent of standard pace. An electric metronome with a flashing light paced the subjects. Each of the subjects within his respective age-sex group was randomly assigned to one of the two tasks at one of the three specified paces, and measured on three different days. Test sessions lasted 40 minutes, with anthropometric data gathering and instructions occupying the first 10 minutes, task practice without wearing the gasometer for five minutes, practice at the pace for five minutes, and work for 17 minutes. The last 10 minutes were used to determine the subject's ventilation rate.

Analysis of variance showed no significant interactions. Only the factors sex, task, and pace were significant ($p < 0.01$). The age variable was not an important factor in determining ventilation rate/BSA while performing tasks. The ventilation rate/BSA for males averaged 9.6 percent greater than for females. Ventilation rates/BSA for filling pinboards averaged 8.8 percent higher than for dealing cards, and were higher for all three paces. As pace increased, the ventilation rate/BSA increased correspondingly and significantly. The relationship between ventilation rate and pace for each task, as well as for each of the subgroups of males and females, is not linear. A one-way analysis of variance test showed that at the 0.05 level no significant difference in ventilation rate for the female subjects was attributed to their ovulatory cycle.

These experiments appear from this excellent report to have been very well conducted. The authors believe that the variability of the mean ventilation rates may have been artificially increased by a too-short prerest period in the resting experiment and by inadequate training for some subjects in the task-performing experiment. Further research, including a longer study of mean levels and use of a greater range of paces and ages, is called for.

9

Baker, Paul T., American Negro-White Differences in Heat Tolerance, Environmental Protection Research Division, TR EP–75, QM R&D Center, Natick, Mass., DDC AD #201 112, (1958a).

Abstract:

This study examined the physiological responses of American Negro and White soldiers under hot-wet and hot-dry conditions to determine differences in heat tolerance. Forty pairs of men (1 Negro, 1 White) in the hot-wet and eight pairs in the hot-dry condition were matched for body fat, weight and stature. The experimental design for each condition was as follows: (1) *Hot-wet*—Each pair was first weighed, dressed, rectal temperature taken, and then walked around a one-half mile course at a speed of 3.5 miles per hour for one hour. At the end of the hour, pulse rate and rectal temperature were again taken, and the men undressed, wiped off all sweat, and were weighed. As far as possible, all variables except weather were controlled; no water intake or urine output was permitted during the test period. (2) *Hot-dry*—Measurements were taken for skin color reflectance for both White and Negro. Each pair rested in a tent in the desert for one hour before testing began, then were weighed, dressed, had rectal temperature taken, and started on one of eight different desert conditions, each of which each man repeated four times. The conditions were combinations of sun, shade, nude, clothed, walking (at 3 mph) and resting. At the conclusion of each trial, rectal temperature, total sweat loss, evaporated sweat loss and pulse rate were recorded.

The results indicated that: (1) Under hot-wet clothed-and-walking conditions, Negroes had a higher physiological tolerance. (2) Under hot-dry nude-exposed-to-the-sun conditions, sun-tanned Whites had a higher tolerance. (3) Under all other conditions, the groups had about equal tolerance. (4) The differences found appeared not to be a function of transient environmental effects and were probaly genetic in origin. This problem needs further study.

Thorough development and discussion of the problem is contained in this study. Two-tailed t-tests were employed for analyses of results.

10

Baker, Paul T., A Theoretical Model for Desert Heat Tolerance. Natick, Mass., Quartermaster Research and Engineering Center, TR–EP–96 (1958b).

Abstract:

This paper attempted to construct, on the basis of the adaptive mechanisms utilized by the human body, the kind of man that would be the most perfectly adapted to hot desert conditions. This problem was divided into three areas: (1) Morphological and racial variables; (2) Genetic and environmental forces acting on (1); and (3) Comparison of the model with the actual world distribution of morphological and racial characteristics. Previous studies supplied information on the various indices of heat toleration, those used in this paper being rectal temperature, pulse rate, sweat loss and the probability of fatal heat stroke. Using figures from other studies, the author constructed theoretical calculations through application of conventional procedures.

Baker concluded that: (1) Genetic factors determined many characteristics which have been affected over time by environmental forces, such as the tanning of skin. (2) Morphologically, the model should be healthy, have low subcutaneous fat, have large surface area per unit weight, have brunette skin color, and be acclimatized to a high level. (3) Comparison of the model to actual world conditions indicated that the model conformed fairly well to desert populations, and that the model could be used to select groups of men who are above average in desert heat tolerance.

This is a very good theoretical study. That the author does not quantify the attributes he proposes for his model is due in large part to the scantiness of the data available on world populations and to the variety of procedures used to collect such data as are available. Body fat, for example, has been estimated by at least three different and not strictly compatible methods, while skin color has most often been judged only subjectively.

11

Baker, Robert A., and Ware, J. Roger. The relationship between vigilance and monotonous work. Ergonomics 9 (2), 109–114 (1966).

Abstract:

It was sought to determine if a subject's behavior on a monotonous vigilance task could be predicted from his performance on other monotonous tasks. Forty subjects (Army trainees), over a period of two days, worked for two hours each on four different routine and monotonous tasks: (1) a simple vigilance task (monitoring 0.05 second interruptions of a 3/4 inch pilot lamp, with twelve signals presented per half-hour at randomized intervals); (2) a sorting task (separating four kinds of dried beans into appropriate channels); (3) a simple assembly task (filling 50-caliber machine-gun shells with one each of four kinds of dried beans and sealing them with a piece of paper towel and a rubber band); and (4) an addition task (two-digit addition problems). The performance measure for the vigilance task was the number of signals detected and the number of signals missed. Performance measures for the other tasks were the number of units completed in the time allowed and the number of errors.

The coefficients of concordance (Kendall's W) were statistically significant. However, no correlation between vigilance and any of the other tasks approached significance, and the high overall relationship was attributable to significant correlations among the other three tasks. It was concluded that the subjects' performance on the sorting task, for example, was predictable from their performance on assembling and adding, but vigilance performance was not predictable from behavior on the other tasks. The vigilance task, therefore, appeared to contain elements not found in other monotonous work. Two of the unique aspects could be the lack of "automaticity" (i.e., mechanization to a degree that frees the subject's attention)

and the inability of the subject to control or pace his work rate.

This was a good study, with background, methodology, results, and statistical treatment well formulated. Further exploration should be made with the authors' suggested variables of automaticity and self-pacing.

12

Balke, Bruno, Gas Exchange and Cardiovascular Functions at Rest and in Exercise Under the Effects of Extrinsic and Intrinsic Fatigue Factors. B. The Influence of Physical Fatigue Upon Work Capacity, Randolph AFB, Texas, School of Aviation Medicine, DDC AD #30 206 (1954a).

Abstract:

Physical fatigue was induced by walking on a treadmill for a period of 60 minutes under two phases of a work load: (1) Control test (Test I): the work load gradually increased from a speed of 3.4 mph with 0.05% pitch increase per minute until the pulse rate reached 180 beats per minute—which was defined as the Optimal Work Capacity (O.W.C.); and (2) Test Procedure (Test II): as soon as O.W.C. was attained, the incline of the treadmill was lowered rapidly and held constant at this new level for the rest of the hour. The experimental design consisted of the following series: (1) Series A: treadmill incline was lowered to 50% pitch occurring at the point of O.W.C.; (2) Series B, 65% of O.W.C.; (3) Series C, 75% of O.W.C.; (4) Series D: Test I, 60 minutes resting period, Test II. Each 60-minute work period was followed by a 60 minute rest period during which no food or drink was allowed, and then the subject returned to repeat Test II of the series he had performed before the rest period. Five subjects participated in all series, one experiment a week, sequence order D, A, C, B, except for Series C which had three additional subjects. All were judged as healthy males, 22–45 years old, $\bar{X}=28$ years. Body weight was taken before Tests I and II for all. Pulse and blood pressure measurements were taken in the second half of each minute. Air was collected in a Tissot gasometer; mixed expired air was then drawn through a Pauling oxygen meter. Readings were taken every 15 seconds and checked with mixed expired air collected in Douglas bags and analyzed in Haldane apparatus. Respiratory volume was recorded photoelectrically.

Results: (1) Pulse rate was directly related to increased work load. (2) The higher the effects of preceding work load, the lower were the values of the systolic pressure. (3) Diastolic pressure remained practically unchanged. (4) Oxygen consumption for Series A and B did not change significantly when compared with the controls; but was relatively high after the severest form of exercise performed in Series C. In spite of this higher metabolic rate, the amount of oxygen taken up per pulse beat was less. (5) Pulmonary ventilation was higher than the rise in oxygen consumption, indicating a decrease of ventilatory efficiency. (6) Respiratory rate increasd with work load. (7) Tidal volume was smaller in the fatigue tests than in the controls. (8) There was loss of body weight during the one-hour period of pre-work in Series A, B, C. (9) Loss of work capacity became rapidly progressive when an individual performed continuous work closer to his O.W.C. (10) It was summated that: (a) cardiovascular and respiratory functions were altered during work under the influence of physical fatigue; (b) physical fatigue caused a decrease of work performance; (c) correlations were found between the amount of work done during the fatiguing work period and changes in work capacity.

This study was poorly developed, discussed, and organized. Statistical treatment of the results are not adequate to support acceptance of the findings without reservation.

13

Balke, Bruno, Optimal physical efficiency; measurement and following fatigue, Arbeitsphysiology **15**, 311–323 (1954b).

Abstract:

This article describes an experiment designed to create and measure the "optimum conditions" in which maximum work performance is obtained. Measurements of heart rate, blood pressure, oxygen consumption, and carbon dioxide release were made during work of different intensities. It was found that the maximum work performance was usually attained at a pulse rate of 180 beats per minute. This is a very good experiment and is very well presented.

14

Barany, J. W., and Greene, J. H., The Force-platform: Instrument for selecting and training employees, Amer. J. Psychol. **74**, 121–124 (1961).

Abstract:

This article consists of suggestions for the use of a force-platform designed and constructed by the Purdue Farm Cardiac Project. The device is a highly sensitive instrument for the measurement of forces exerted by an operator over a period of time and is sensitive enough to detect the heart beat of an individual standing on the platform. Sample graphs were presented of the frontal forces exerted by three male subjects pushing a foot-lever with a 35 lb force at a rate of 44 strokes per minute, and the various differences in the force-patterns of the three subjects were discussed.

In the area of applied psychology the force-platform could be used for the selection and training of employees: to test an applicant's ability to establish a rhythmic pattern of movement with few extra or false motions; to present graphic representations to worker trainees of their motions in a particular work cycle; or to determine an ideal work pattern for use as a model in improving worker performance. In the area of pure research, the force-platform could be employed: to study the onset of physiological fatigue with its accompanying loss of coordination; for experiments concerned with the acquisition of motor skills; for analysis of movements in reaction-time studies and in learning experiments; or in comparative psychology to measure the reaction of a rodent to electrical shock or some other noxious stimulus.

15

Bartlett, Sir Frederic, Symposium on fatigue; (A) laboratory work on fatigue, Royal Society of Health Journal, London **78** (5), 510–3 (1958).

Abstract:

A brief historical review of fatigue research is presented. Studies at the turn of the century on isolated muscle groups with a dynamometer or an ergograph indicated that muscular work accomplished less and less with repeated contractions. Study of mental fatigue also involved repeated simple activity, and it was thought that when there was fatigue there must also be work decrement and vice versa. It slowly began to be realized that fatigue was a process having its own and internal features, though the basic procedure of research remained unaltered. Studies of pilot fatigue during World War II indicated the complexity of factors (both display or perceptual factors and control or action problems) involved in fatigue of skilled behavior.

The author believes that, in dealing with whatever activity, the notion that there can be a straight work decrement criterion of fatigue is all wrong. There is neither a single criterion of fatigue nor can there be any simple satisfactory test of fatigue or of fatiguability. Recent studies have established the fact that unwanted effects of continued exercise may be considerably delayed in their expression, and much more research is needed on the cumulative effects of fatigue.

16

Bedford, Thomas, Thermal Factors in the Environment which Influence Fatigue, in W. F. Floyd and A. T. Welford, eds., Symposium on Fatigue, chap. 2, pp. 7–17, (H. K. Lewis and Company, London, 1953).

Abstract:

The effects of heat and humidity on the thermal comfort, working efficiency, accident liability, and health of industrial workers are discussed with references to several British studies. Various scales of warmth have been used as measures of heat, humidity and speed of movement of the air, and the heat radiation from the surroundings: (1) *The Kata Thermometer* indicates the "cooling power" of the environment, and can be also used as an anemometer. The dry bulb kata is influenced by radiation and convection, while the wet bulb kata is also affected by atmospheric humidity. (2) *Effective Temperature* is based on the equivalence of thermal sensations for various combinations of air speed and dry-bulb, and wet-bulb temperatures, but makes no specific allowance for radiation. (3) *The Corrected Effective Temperature*, though not yet adequately tested by experiment, attempts to adjust the effective temperature reading for the presence of heat radiation. (4) *The Equivalent Temperature* is a measure taken by an eupatheoscope of temperature, air speed, and radiation. As it ignores humidity, it is much less suitable as a measure of high temperatures than of normal temperatures.

The author concludes from his analysis of several studies that, although in certain situations (such as firefighting) it may be necessary to push men to the limits of endurance for short periods, ". . . for active, yet not heavy, work when people must be clothed the wet-bulb temperature should not exceed about 72° F".

17

Benson, A. J., and Dearnaley, E. J., Estimates of Ability During A Fatiguing Task With and Without Competition and Measurement of Electromyographic Activity in Muscle Groups Not Directly Involved, Institute of Aviation Medicine, Royal Air Force, Farnborough (England). Rept. No. 1089. DDC AD #230 807 (1959a).

Abstract:

This is a preliminary study of two possible approaches to the general problem of fatigue and motivation. The first approach was the measurement of electromyographic (EMG) activity in muscles not engaged in a primary task. The second was to ask the subject what he would be prepared to undertake. Ten males, ages 20–32, sat at a table and were instructed to pull on a double-handled isometric strain gauge myograph which S held just in front of his chest. The ouput could be viewed by S on a microammeter, as he was to keep the tension of the pull at 10 kgm. Muscle action potentials from the gastrocnemius soleus muscle group were also recorded. There were three stages in the experimental procedure, each separated by a five minute rest: (1) S was instructed to hold the pull at a constant tension, estimate how long he could maintain this, and then begin the task. At 15-second intervals, he was asked how long he could maintain tension; after 20-seconds, EMG readings were taken until 30 seconds after the trial. Lastly, S was asked to state why he gave up and what feelings and sensations he experienced. During this trial, S could not view the microammeter. (2) and (3) were similar to each other, except that in one, the subject was told he was competing for a prize and in the other, he was serving as a control. In both instances, S had view of the microammeter.

Results indicated that: (1) On the average, the offer of a prize increased the time for which the subject pulled. (2) When the S had no error display, the tension with which he pulled decreased over the duration of the pull, and the mean time for which he pulled was longer. (3) On the average, the rate of increase in EMG activity with time was greatest under competitive conditions, and least when there was no competition and no error display. (4) The rate in increase in EMG activity was primarily determined by the motor effort demanded of the subject, but this could have been influenced by the level of motivation or arousal. (5) Estimates made increased with time and were most accurate for the last trial.

This is a good study exhibiting adequate methodology and good development and discussion of problems and results.

18

Benson, A. J., and Dearnaley, E. J., Estimates of Ability During Iterative Performance of a Fatiguing Task and Measures of Electromyographic Activity in a Muscle Group Not Directly Involved, London, Flying Personnel Research Committee, Rept. 109, AD #237 774 (1959b).

Abstract:

This study examined the relationship between the patterns of increasing electromyographic activity and estimates of duration on an isometric myograph held at a constant tension. Twenty pilots were instructed to pull on a double-handed isometric strain gauge myograph (held in front of his chest) to a 10 kg tension; they were to estimate the longest and shortest period they could maintain this tension. During the trial the subject was asked at 15 second intervals how much longer he could maintain the tension. After the trial, S was asked to state why he gave up and what sensations and feelings he experienced. Muscle action potentials were recorded by electrodes in the left gastrocnemius soleus muscle group 20 seconds after the trial started until 30 seconds after the trial ended. There were three trials, separated by 5 minute rest periods between each pull. A practice period preceeded the testing.

Results: (1) The first pull was significantly longer than the second or third ($p < 0.01$); but there was no significant difference between the second and third. (2) Electromyographic activity increased with activity to a maximum immediately prior to capitulation, after which the activity decreased with a steeper slope. Specifically, there were appreciable differences between subjects' patterns of activity of increasing EMG activity. On the average, this increase followed a rising exponential time course and was steeper for the second and third pulls. (3) Accuracy of estimations of duration increased with practice. There was a significant difference ($p < 0.05$) between the first and second pull estimations concerning total duration and reports at 15 second intervals. (4) Rapid learning was apparent in both the initial estimates made before the task and the level of uncertainity within which they were made, and in the estimates made during the task. (5) Intercorrelations of the EMG recordings, estimates, and psychological data did not prove significant. However, the authors attributed this lack of significance to the small population size, and suggested that with a larger sample, significant findings would occur.

This study exhibits good methodology, development, discussion, and statistical treatment of the results.

19

Bilodeau, Edward A., Rate Recovery in a Repetitive Motor Task as a Function of Successive Rest Periods, Journal of Experimental Psychology, **48** (3), 197–203 (1954).

Abstract:

While most research in motor skills learning involves relating recovery to one particular rest period, this project studied the cumulative effects of a series of rests. Basic airmen trainees at Lackland Air Force Base were divided unsystematically into five groups of 54 each. Each individual was given ten, 30-second trials at turning a crank. Intertrial rest was varied between the groups, with a 0, 10, 30, 90, or 180 second rest period interpolated between the 30-second work trials. Subjects were not told beforehand about either the duration or number of either the work periods or the rest periods, but were instructed to rotate the handle as fast as possible between go and stop signals. The number of crank revolutions produced per successive 10-second portion of the 30-second work trial was recorded. Thus, both the recovery from the end of one trial to the beginning of the next and the decrement of performance within each trial were measured.

The within-trial performance trend was negative for all five groups, and was greatest for the longest resting group and least for the shortest resting group. At every point, the groups were ranked from that with the longest to that with the least interpolated rest. The typical rest recovery function—increasing and negatively accelerated—was found for the first two rest periods, but with subsequent rests, the amount of recovery increased progressively for the groups with the shorter rest periods, but decreased progressively for those with the longer interpolated rests. This trend continued until the groups with 30-second and 90-second rests had exchanged rankings. Tests with the 10-second group and the 90-second group were replicated, using 20 instead of 10 work periods, and a trend test

(significant beyond the 0.01 level) indicated that after rest seven, the amounts recovered by each group were equal and decreasing.

Pacing appeared to be adjusted rapidly within each group, and after trial two the successive differences between rest and no-rest groups increased slowly. The progressive drop in recovery for the longer rest groups was attributed largely to decrement in starting rate, and the increase in recovery for the short rest groups was attributed to relatively greater decrement in terminal rates. The author believes that, ". . . after the initial period of adjustment, much (but not all) of the score variance can be accounted for without recourse to differential *accumulating* effects of successive interpolated rests or changing effects of differential rests."

20

Bitterman, M. E., and Soloway, E.. The relation between frequency of blinking and effort expended in mental work. Journal of Experimental Psychology **36**, 134–136 (1946).

Abstract:

This study examined the effect that increased mental activity has on the frequency of blinking. Ten subjects worked for four 15-minute periods on the clerical test in the Minnesota Vocational Test for Clerical Workers under controlled conditions. The variable was a voice being played at 60 dB reciting numbers varying from one to ten digits in length for two of the periods. There was no significant difference in the accuracy scores under the two conditions. The only significant difference was in the increased heart rates during the noise conditions, this being associated with increased muscle strain as a result of increased efforts to concentrate. *There was no difference in the frequency of blinking in any condition.* This study lacked adequate statistical treatment and was too limited in its scope and execution of the problem.

21

Blake, Mary A., and Proctor, Lorne D., The Development of Performance Tasks Producing Fatigue in Man and Other Primates, Symposium on the Analysis of CNS and Cardiovascular Data Using Computer Methods. L. D. Proctor and W. Ross Adey, eds., NASA SP–72 (1965).

Abstract:

This is a symposium paper presented on the development of performance tasks that would induce fatigue in man and other primates to be used in later studies to determine if EEGs could be associated with fatigue and thus used as fatigue indicators. A partial simulated space flight situation was used as a test area for 160 orbits with five monkeys, 50 orbits with seven humans and training data from three chimpanzees. Comparisons were drawn for each subject's early and late performance in an orbit.

Monkey orbits: A number of tasks were developed to assess accuracy (percent correct) and output (percent attempted) of performance. It was ascertained that: (1) in a symbol-matching-learning task, there was no decrement in performance; (2) in a non-matching task, there was no learning and thus no performance; (3) in a symbol-matching-with-interfering-information task and reversal tasks, if the animal could learn the task there would be no decrement in performance; but if the task became boring, accuracy and then output was negatively effected; (4) using shock treatment was detremental to accuracy and output; (5) sugar-pellet rewards maintained high levels of accuracy and output with little decremation in performance over a 48-hour period.

Chimpanzees: Testing was continued and it was found that these animals lacked the flexibility to perform reversal tasks. To compensate for reversal task performance, experimentation is being done with a tick-tack-toe task using lit windows.

Man orbits: Performed tasks similar to those with the monkeys, only at a higher level. Findings: (1) A more complex task does not necessarily cause the subject to be more vulnerable to the effects of fatigue. (2) With a boring task and required vigilance, performance decrements resulted; whereas, with no required vigilance, performance was better. (3) Prefatigued subjects exhibited performance decrements—most errors being attributed to omissions. Another source of accuracy decrement was the vast scope of inattentiveness, again most errors being omission rather than commission. Comparing these two suggested that deterioration of accuracy was no more rapid with prefatigued subjects than with fresh ones. (4) Having subjects assess why they made an error was expected to be an aid in identifying error-causing problems to be studied later. (5) The tests were reported to be already sensitive to response latency. The response time was minimal for subjects in peak performance condition. When they slow down they are credited with more mistakes.

The discussion section concerned analyses of research by Dr. Harold Williams on fatigue and sleep loss.

This is a symposium paper presented on studies that were done to develop performance tasks that would induce fatigue in man and other primates. As a result, there are no statistical procedures presented. and the value of the findings cannot be judged.

22

Botwinick, J., and Shock, N. W., Age differences in performance decrement with continuous work, Journal of Gerontology **7**. 41–46 (1952).

Abstract:

An exploratory investigation was made of age differences in decrement in speed and accuracy of response to continuous repetition of paper-and-pencil tasks. Subjects were drawn from the staff and patients of Baltimore City hospitals and from the City home for the indigent aged. Subjects were divided into two age groups—50 subjects 20 to 29 years, and 50 aged 60 to 69. All subjects were Caucasian, of both sexes, were born in English-speaking countries. and had a minimum of four years education. Six tasks involving speed of response were individually administered in the following order: speed of (a) writing digits and (b) writing words; addition of (c) 3 digit. (d) 6 digit, and (e) 9 digit problems; and (f) digit substitution in the subtest of the Babcock-Levy Scale. Although the tasks were presented as one continual test, there was a lapse of a few seconds between tasks. Each task was subdivided into two to five work units for decrement scoring purposes. Data were analyzed by determining the slope of the linear regression line of performance rate on the work unit number for each individual for each task.

Decrement in performance rate was found for all tasks except for speed of writing digits, which had an increasing rate with successive work units. Significant age differences ($p < 0.01$) in the decrement relationship of speed of response to continuous repetition of the performed tasks were found in all the remaining tasks except writing words and 9-digit addition. Larger work decrements were made by the younger group of subjects, but both the initial and final levels of performance in every task (for both total rate and correct rate of response) were greater in the younger group than in the older subjects. Controlling for education differences indicated that the higher education level of the younger population was not responsible for their larger performance decrements. Sex differences in slope were not found to be significant. Large individual differences were found, and these may have been due to blocking.

23

Bourguignon, Andre, Muscular fatigue measurement. Semaine des Hopitaux de Paris **30**, 655–657 (1954).

Abstract:

This article presents a general review of some methods for measuring muscular fatigue and describes the application of G. Bourguignon's method in the author's own laboratory. It is concluded that the major causes of pathological fatigue are: progressive muscular dystrophy, myostheny. Addison's Disease, and chronic occupational intoxication by various chemicals.

24

Bowen, J. H., Hussman, T. A., and Lybrand. W. A., Indicators of Behavior Decrement: A Review of the Literature on Induced Systemic Fatigue, Department of Psychology, University of Maryland, ASTIA AD #31307 (March 18, 1952).

Abstract:

This report reviews the literature (94-item bibliography) on general systemic fatigue, oriented towards problems of definition and methods of inducing systemic fatigue. The search was concerned more with psychological factors than with physiological or industrial ones. The problem of defining fatigue is commented on, and some definitions in the literature are discussed, classified into physiological, work decrement, and psychological. The methods used to induce fatigue are classified and evaluated under the following categories: sleep deprivation, work periods, ergographic techniques, psychomotor tasks, and physical exercise tasks. In view of the confusion regarding the definition of fatigue, the authors suggest that operational definitions of assumed behavior decrement producing variables be adopted. Ergographic and normal workday techniques are not recommended, as the former are too limited in applicability and generalization, and the latter offer little opportunity for adequate experimental control.

Task-produced behavioral decrement has been shown to be relatively task specific, and experiments must be rigidly controlled. Sleep deprivation and physical exertion methods are recommended for the project for which this literature search was made.

25

Brouha, Lucien, Fatigue—Measurement and reduction, Industrial Medicine and Surgery, Vol. 22, 547–554 (1953).

Abstract:

This is a general discussion and review of several studies of fatigue in industrial workers. The author states that situations leading to physiological stress and physical fatigue can be evaluated by measuring the pre-work resting rate, the physiological stress, and the recovery rate of variables such as: heart rate, blood pressure, cardiac output, pulmonary ventilation, oxygen consumption, chemical composition of the blood and urine, body temperature, and rate of sweating. Several methods of measuring and evaluating the stress and ways to reduce fatigue are discussed, with examples from numerous in-plant studies.

26

Brouha, L., Factors Influencing the Physiological Reactions to Work at Moderate Temperature, Physiology in Industry, chapt. 1–2, pp. 14–38 (1960a).

Abstract:

The material is discussed under the following headings:

(1) *Influence of the kind of muscular activity.* A person who is able to reach a high steady state of oxygen consumption and to recover quickly from repeated efforts will achieve a high level of physiological efficiency. The time for final recovery to the resting state depends on the total amount of exercise performed and the total amount of rest taken: the more work and the less rest, the longer it takes to recover and vice versa.

(2) *Influence of individual factors.* Age, sex, fitness, and nutrition influence quantitatively the adaptation processes to muscular work. Physiological age, not chronological, is the real age factor which influences the capacity for muscular work. Men and women show marked differences in their physiological capacity for work. Two studies mentioned here indicate that women are the "weaker sex," being less fit than men for both moderate and strenuous exertion and exhibiting less endurance for this type of activity. At a given level of oxygen intake, the heart rate is higher in women than in men, and conversely, for a given heart rate, men achieve a greater oxygen transport than women during submaximal and maximal work. The aerobic capacity is 25 to 30% lower in women. "The fitness of the individual is probably the most important factor determining the level of physiological reactions to exercise."

"Among the responses to exercise which differentiate the fit from the unfit may be listed:

(1) More economical ventilation during exertion;
(2) ability to attain a greater maximum ventilation;
(3) greater mechanical efficiency as measured in terms of lower oxygen consumption for a given amount of external work;
(4) ability to attain a greater maximum oxygen consumption;
(5) lower gross respiratory quotient (R.Q.) during exercise;
(6) lower blood lactate for a given amount of exercise;
(7) ability to push self to a higher lactate before exhaustion;
(8) less increase in pulse rate for submaximal exertion;
(9) quicker recovery in pulse rate following activity;
(10) ability for the fit and the unfit to attain the same maximum heart rate, but the fit subject performing more work before reaching that level."

The estimate of capacity to do muscular work should be based on the subject's actual ability to perform it and on the speed of recovery after exercise. Except for well-trained athletes, measurements taken at rest have little or no relation to the performance capacity of the individual. Nutrition—the caloric requirement increases with the amount of work performed. Cases of malnutrition are more common than generally realized even by the medical profession. A survey of 110 workers indicated their diet was satisfactory in calories, proteins. and vitamin A; but was deficient in thiamine, riboflavin, nicotinic acid, ascorbic acid, and vitamins B and C.

(3) *Training and Variability within the Individual.* More research is needed on the subject of what happens during training, and why. Training increases the size of skeletal muscles, improves the transmission of nerve impulses to the motor units and the precision and economy of any motion or sequence of motions, increases the efficiency of the heart, affects the blood pressure, improves the cardiovascular recovery processes, modifies the blood distribution, and changes the respiratory responses. After a few weeks of training, improvement ceases and performance levels off. If the work *rate* is then increased, performance will rise to a new and higher plateau. This procedure can be repeated several times.

27

Brouha. L., General Effects of the Physical Environment, Physiology in Industry, chapt. 2–1, pp. 39–46 (1960b).

Abstract:

Man can survive, and function, under a wide range of external stresses, but it is only in a favorable environment that he can produce sustained and repeated effort and at the same time remain in good physical condition. Adverse conditions of the environment can transform an easy task into a hard one. The most common and important environmental factors which influence the worker's physiological behavior are: temperature, humidity, air movement, and atmospheric contaminants. This chapter deals primarily with the effects of heat and humidity upon performances. It ignores completely work done by P. T. Baker and others on racial differences in acclimatization and performance under heat stress. Wide individual differences are noticeable even in heat acclimatized subjects and cannot be explained by age, body size, sex, or fitness. For the same amount of work, the man experiences an increasing physiological strain as the temperature of the environment rises. There needs to be much more work done on subacute heat stress in industry, because there is no accumulating information by industrial medical departments on the long-term effects of subacute heat exposures. It is therefore very important to evaluate accurately the heat stress and to determine how it affects the reactions of workers in industry.

28

Brouha. L., Evaluation of Heat Stress, Physiology in Industry (1960c).

Abstract:

Workers exposed to the same heat stress when "on the

job", exhibit a wide range of physiological strain. This excellent study investigates physiological reactions to different work loads at different controled temperatures and humidities. Two experiments:

(1) *Effect of Continuous Work:* 6 males and 6 females on bicycle ergometer for 30 minutes steady work. Recorded heart rate. respiration. O_2 consumption, and CO_2 production. Showed increasing degree of stress from normal temperature and humidity to both warm-dry and warm-humid conditions. Believes that O_2 consumption measurement alone may be misleading. Warm-dry condition appears to be better than warm-humid.

(2) *Effect of Repeated Work Cycles:* 4 males and 4 females pedaled bicycle ergometer for 10, 5-min. rides, with partial heart-rate recovery in between. Measured heart rate, oral temperature, and body weight. Heart rate and recovery time increased from the first to the 10th cycle. No steady state could be maintained even under the most favorable conditions. Conditions—normal, cool, hot-dry, hot-humid demonstrates the fallacy of using fixed-length rest periods in industrial operations. Rest periods need to be increased in length as work cycles are repeated throughout the shift and as the temperature becomes warmer. Clothing and certain protective equipment can increase stress by hampering heat dissipation. More research is needed on "clothing stress."

29

Brouha, L., Evaluation of the Physiological Requirements of Jobs, chapter 3–1 of his book, Physiology in Industry (1960d).

Abstract:

This is an excellent review of several physiological studies of various industrial jobs, and a plea for physiological research in addition to the standard time-motion study.

The author believes that the work load and the environment are the most important measurable variables. Work intensities can be classified according to O_2 consumption, energy expenditure, heart rate (pulse), and cardiovascular reactions. The energy expenditures in calories per minute are presented for various occupations.

Author works mainly with "heart rate recovery curves," which show the changes in heart rate at 1, 2, and 3 minutes following completion of a task or work cycle. Found that the heavier the work load, the higher the heart rate during recovery and the more slowly it returns to its resting level. The better the physical capacity of the individual, the smaller the increase in his heart rate for a standard work load and the more rapid the return to its resting value. The experiments reported were usually controled by using the same men in before and after situations.

When the average value of the first recovery pulse is maintained at or below 110 beats/min, and when the deceleration from the 1st to the 3rd minute is at least 10 beats/min, no increasing cardiac strain occurs as the work day progresses.

Presents a summary of a "typical" physiological survey at a Chemical Plant.

Uses a *force platform* measuring minute forces exerted in 3 directions for evaluating the work pattern in light work, which doesn't cause measurable cardiac strain. By studying the efforts involved in several sequences of motions leading to the same final result, the author believes that the most efficient and least tiring order of performance can be determined.

Most studies of motions and work have concentrated on *time*—the *physiological* factors need also to be investigated.

30

Brouha, L., Reducing Stress and Fatigue: Evaluation of Improvements, Physiology in Industry, chapt. 3–2 (1960e).

Brief Abstract:

By measuring heart rate recovery and changes in body temperature, the author evaluates the influence of many factors contributing to the strain and fatigue of the industrial worker. Several studies are discussed in brief, with their results presented in tabular and graphic form, in the analysis of the following ways of reducing fatigue and improving performance: reducing the work load, reducing the heat load, establishing adequate rest periods, organizing workers teams, alternating work in different environments, and compensating for sweat loss. The various studies involve these steps: determining the work cycle, measuring environmental stresses and the strain responses modifying the stress-producing situation, taking physiological measurements again, and evaluating the results. Asks for the replacement of the "time-motion work cycle" by a "physiological work cycle." Provides a first class overview of the subject.

Extended Abstract:

By measuring heart rate during recovery and changes in body temperature, it is possible to evaluate the fatigue of the worker. The author presents several examples of reducing stress in industrial situations and evaluating the physiological benefit of the change.

(1) *Reducing the work load.* What counts is not the mechanical work, but the "physiological work" necessary, and which will produce fatigue sooner or later. Many industrial operations can be made easier if the position of the body (static contraction), the nature of the motion (dynamic contraction) and the speed of motion (rate of contraction) are so arranged that the physiological cost of the job is reduced to a minimum. Uses heart rate recovery curves as a measure of physiological cost; and a force table for measuring light work.

(2) *Reducing the heat load.* This can be effected by reducing humidity and increasing ventilation, using an air-permeable ventilated suit and/or helmet. by protecting the workers with special screens, and by developing tools and methods which will enable the worker to work as far as possible from the source of heat. A ventilated suit considerably reduces the stress produced by physical labor and heat exposure, and also protects against fumes, gas, and dust. Air-conditioned rest areas are being used by Alcoa and Dupont to facilitate complete and rapid recovery of workers exposed to severe heat stress at work.

(3) *Adequate rest periods.* When a standardized system of work- and rest-periods was instituted for men working with very hot furnaces, heart rate recovery and body temperature improved definitely. Rest and work periods were each shortened in the second half of the 8-hour shift to counteract the buildup of strain and fatigue. Production did not fall off in the summer, as it had before, and absenteeism and turnover were markedly reduced. Another study showed that work crews could be reduced 25%—from 4-man crews to 3-men—without producing any abnormal physiological strain, under the improved work conditions. Optimum duration as well as scheduling of rest periods should be determined in relation to shift progression and temperature changes if maximum benefits are to be obtained.

(4) *Organizing worker teams.* In certain operations where several men are involved, it is sometimes found that, in spite of improvements, the physiological stress remains too high when the working team comprises the smallest number of men compatible with the job. In these instances, adding men to the team decreases individual physical exertion, increases resting time per man, and often increases production enough to offset the cost of the added workers.

(5) *Alternating work in different environments.* 6 male subjects walked treadmills in cool and warm workrooms with less than 30 seconds in between. On the basis of the maximum heart rate during work, the stress was similar in going from cool to warm and from warm to cool. The cardiac debt. however, was 39% smaller when the work cycle progressed from warm to cool conditions, and heart rate recovery was faster. When the subject works first in the heat, he is able to pay part of his heat debt while he continues working in a cooler environment.

(6) *Compensating for sweat loss.* Under the usual circumstances of exposure to industrial labor and heat, it is advantageous to replace the sweat loss on an hourly basis (by drinking water) and to replace sodium chloride by adequately salting the daily meals. Salt tablets are then unnecessary.

Describes a study in material handling which uses the above factors in combination. First determined the weight that

could be handled without putting "undue" stress on the worker. Heart rate recovery was the measure used. Modified a machine and effected a 25% economy in energy expenditure. Determined the most efficient rate of work and most effective environment, analyzing work at 72. 80. and 84° F. effective temperature. Temperature affected heart rate and cardiac cost adversely more at the faster work rate than at the slower. Stress could be handled well at 72°, but was very definite at 84° F. effective temperature.

General Conclusion—Physiological techniques should be introduced in the methods of work analysis and work measurement. The concept of "time-motion work cycle" should be replaced by "physiological work cycle," which includes not only effort per unit of time multiplied by duration of operation but also takes into account the physiological recovery time.

The results of each Study summarized are presented in tables and graphs. The original environmental conditions and stress produced, the changes instituted, and the quantified results are all given.

31

Brouha, L., Selection, Placement and Supervision of Workers, Physiology in Industry, chapt. 3–3, pp. 140–145 (1960f).

Abstract:

Wide physical and physiological differences are found among individuals, even when studying men who appear to be thoroughly adapted to their work. A step test of endurance given to 2167 male college students produced scores on a "physical fitness index" ranging from 15 to 155, with an M of 75 and an SD of 15.1. Differences in pulse rate during work and in heart recovery rate are also found in light work. Removing the physically unfit for a particular task will improve both the efficiency and morale of the remaining workers. Stress can be decreased by: (1) improving environmental conditions, (2) designing machines and tools for maximum efficiency with minimum physiological cost, (3) selecting workers on the basis of their physiological fitness for specific tasks. A study of 1510 employees performing the same task, involving heavy physical labor and heat exposure, showed that workers aged 40 to 50 years averaged a pulse rate 10 beats per minute faster during recovery than workers aged 20 to 40. It is concluded that the factor of aging should be given more consideration by employers, and that the usual policy of keeping an individual on the same job for long periods of time should be challenged if the job can be classified as moderate or heavy work.

32

Brouha, Lucien, and Maxfield. M. E., Practical evaluation of strain in muscular work and heat exposure by heart rate recovery curves, Ergonomics **5** (1), 87–92 (1962).

Abstract:

Evidence was presented in support of the contention that in any environment the work rate may be indicated by the rate of oxygen consumption and physiological strain induced in the subject by the heart rate response. Experiments were performed in a climatic room that permitted control of environmental conditions. Continuous measurements were made of heart rate (using chest electrodes and a cardiotachometer) and oxygen consumption (using a pneumotachometer, an oxygen and carbon dioxide analyzer, and an analogue computer to perform the calculations necessary for a continuous record). Body weight and oral temperatures were also recorded at the beginning and end of an experiment.

(1) Effect of environmental temperature on oxygen consumption and heart rate during intermittent work: Two laboratory workers, a 29-year-old woman and a 35-year-old man, following a 20-minute rest period, pedalled a bicycle ergometer at a constant work rate for 8 or 10 successive periods of 5 minutes each. The intervening rest periods were just long enough to permit the oxygen consumption to return to its pre-exercise resting level. There were two environmental conditions: comfortable (DB 72° F., RH 50%) and uncomfortably warm (DB 91° F., RH 97%). It was assumed on the basis of previous studies that work performed in uncomfortably warm surroundings was associated with physiological strain. The results: Oxygen consumption behaved similarly in both conditions, maintaining a steady state at similar levels in successive cycles. The heart rate curves in the two environments. however, differed markedly, attaining a relatively steady state in comfortable surroundings, but increasing during each work period and ending at progressively higher levels with each successive cycle in the warm environment. The heart rate evidence of increased strain was also supported by changes in oral temperature and body weight, the changes being greater in the warm environment than in comfortable surroundings.

(2) Heart rate as indicator of physiological strain induced by work in a constant environment: A 29-year-old woman. a 35-year-old man, and a 15-year-old boy. following an initial rest period pedalled the bicycle ergometer or walked at the rate of 3.2 m.p.h. on a treadmill for 15 minutes. The work rate was varied by changing the resistance against which the subject pedalled or by altering the slope of the treadmill. The results: Cardiac cost (a measurement of the area under the heart rate curve obtained by plotting the rate for each minute of work and recovery) increased in a positively accelerating amount as the work increased. It was also demonstrated that recovery heart rates (counted during the final 30 seconds of the first. second, and third minutes of the recovery period) could be used if a continuous measurement of heart rate was impractical.

(3) Heart rate as an indicator of physiological strain induced by a constant work load in environments of varying stress: Four male college students underwent a series of experiments. Each experiment consisted of a 15-minute rest period followed by four work cycles. each cycle including a 15-minute walk at 3.2 m.p.h. on a horizontal treadmill, followed by a 20-minute recovery period. The temperature of the environment was varied to induce different degrees of stress in the subjects. The results: The increasing stress-environments led to progressive increases in cardiac cost. Recovery heart rates were again shown to be an accurate measure for total cardiac cost.

Although this study does not conform to rigid methodological requirements usually desired in controlled experimentation, it is a very good study for its type. using precision measurements of physiological variables. The subject sample was small (only 2 to 4 subjects). and no statistical analysis was applied to the data. All the authors' conclusions were made from inspection of the curves which resulted when the experimental data were plotted on graphs. Nevertheless, there seems to be strong evidence for accepting the authors' conclusions. for the curves plotted showed little scatter and seemed striking evidence for the existence of functional relationships. Graphs are included with the text. Recommended are larger samples in future experimentation and a more complete reporting of procedure.

33

Brown. I. D., Studies of component movements. consistency and spare capacity of car drivers, Annals of Occupational Hygiene **5**, 131–143 (1962).

Abstract:

Work at the Applied Psychology Research Unit, Cambridge. on the objective measurement of automobile driving behavior in real-life situations is summarized. The first method attempted was that of measuring component movements of the car using a pen recorder which indicated the position and movements of the accelerator, brake, clutch. steering wheel. etc. Preliminary results indicated that drivers might be performing the same task with equal skill but with completely different behavior patterns, and the measure was insensitive to individual differences. Measuring the position of the car on the road in relation to other traffic was attempted by using movie cameras. Errors in steering could not. however, be distinguished from genuine evasive action, and scores could not easily be quantified. Assuming that consistency would be an indicator of driving skill, the centrifugal forces imposed by a driver on his car while rounding "standard" corners six weeks apart were measured and compared. Police and rally drivers were found to be more consistent by this measure than were less-skilled drivers. The measure discriminated between easy and difficult corners, but did not appear to be sensitive to fatigue.

Finally, it was decided to measure the reserve, or "spare capacity" which a driver is able to draw on in an emergency when very rapid decisions have to be made. After training, drivers were tested 10 times on different days while driving in a residential area of light traffic and presumably a light mental load, and in a shopping area with heavy traffic and imposing a heavier mental load. A subsidiary task was used to test the driver's spare capacity, as follows: A continuous series of 8-digit number groups were presented audibly to the driver at 4-second intervals. Seven of the digits in each group were the same as in the preceding group, but one was different, and the driver was asked to detect the change and call out the new digit before the next group was presented. The percentage of correct responses was significantly lower when driving in shopping areas than in residential ones ($p < 0.025$, Wilcoxon Test).

Two types of subsidiary tasks were compared in a study of police drivers before or after a duty tour. In an "attention" task a series of digits was presented and the driver was to detect a sequence of 3 digits in the order odd-even-odd. In a "memory" task, 10 letters were presented, one every 5 seconds. Nine were dissimilar, and the task was to state which letter was repeated. The attention task gave measures of spare capacity which differed significantly between the 2 conditions (before and after 8 hours of driving), while the memory results did not. The memory task had a greater effect upon the task of driving than did the attention task. The accelerator, brake, clutch, and steering wheel were used about the same number of times during a test run whether a subsidiary task was performed or not. There was, however, a tendency towards a reduction in average speed when a subsidiary task was performed.

34

Brown, J. R., Environmental aspects of fatigue, Applied Therapeutics, Vol. **6**, 905–910 (1964).

Abstract:

This is a general, introductory overview of the relationships between environmental factors and fatigue. Included are such aspects as homeostasis, muscular fatigue, posture, fixed positions, thermal environment, water loss, salt loss, adaption to cold, visual and auditory fatigue, and the effects of fatigue. Many of the statements made are supported by literature citations, but too many are not. The author concludes that, since the environment, both natural and man-made, modifies the amount of physical effort that may be carried out before a state of fatigue is reached, it is necessary that the environment be controlled so that physical demands on the individual will not affect his health and well-being.

35

Brozek, J., and Simonson, E., Visual performance and fatigue under conditions of varied illumination, American Journal of Opthalmology, Vol. **35** (1), 33–46 (1952).

Abstract:

The effects of varied intensity and spectral composition of mixed white light were studied using a specially designed work test, a series of tests of visual functions measured before and after 2 hours of work, and a discomfort questionnaire administered at the completion of each testing session. The visual work involved recognition of small letters moving past a narrow slit so as to be exposed for less than 1 second each. The design of the main series of experiments involved 3 factors—intensity of illumination (2, 5, 15, 50, 100, and 300 foot-candles), spectral quality of illumination (all were mixed white light, but 1 had a slight green tinge and another a slight blue tinge), and subjects (6 "healthy young men in their twenties with normal vision"). The stress conditions used to establish the limits of deterioration involved strenuous visual work carried on for 2 hours at 2 foot-candles and for 4 hours at 5 foot-candles, and were close to the limit of tolerance. The following tests were made both before and after each experiment: (1) Recognition time for threshold-size dots and flicker fusion frequency, (2) Opthalmologic tests (abduction, adduction, vertical convergence, accommodation near point, and convergence near point), (3) Opthalmograph (eye movements), and (4) Brightness discrimination. The results were analyzed in terms of a complex analysis of variance, yielding sensitive tests of the statistical significance of the differences between the mean scores obtained under different conditions of illumination. In addition, a biologic evaluation of the relative importance of the differences between the experimental conditions was attempted. The average performance, the performance decrement, the average blinking rate, and the change in the recognition time differ significantly at the 3 levels of illumination analyzed (5, 100, and 300 foot-candles). There was not, however, a significant difference in the change of flicker fusion frequency, the change in the rate of eye movements, or in the discomfort score. The authors state that the limits of this experiment did not reach a biological "zero" with reference to which the relative amount of deterioration should be expressed. The existing literature on the effects of spectral quality of light presents by no means a consistent picture, and does not include data strictly comparable to the results reported here. The authors state that the differences in the spectral quality of the 3 light sources could be perceived only when they were being directly compared, and were not apparent when 1 source was used alone. *This is a very good study, and needs to be replicated* using more subjects and subjects of different ages, sex, and physical conditions.

36

Bullen, Adelaide, New Answers to the Fatigue Problem. Gainesville, Fla., University of Florida Press, p. 176 (1956).

Abstract:

Original research on human fatigue using the Sheldonian body type-temperament approach is presented in a nontechnical anecdotal, popular style. Following a simplified discussion of 7 body types and their concomitant temperaments is a chatty discussion of how people feel and behave in an office and a factory. Some findings of laboratory experiments on nervous and mental fatigue in relation to body type are also presented. Laboratory and field methods are not discussed. This book is not worthy of serious consideration.

37

Byck, R., and Hearst, E., Adjustment of monkeys to five continuous days of work, Science **138** (3536), 43–44 (1962).

Abstract:

Four mature male rhesus monkeys were subjected to a 120-hour fatiguing task which involved lever-pressing to avoid an electric shock. All monkeys had been trained to press a lever in order to prevent an electric shock to their feet; any pause in responding longer than 5 seconds produced a 5 to 6 mA shock of approximately 0.5-second duration. Improvement in avoidance of shock increased over time by the monkeys' adjusting to the situation by changing their work methods, either through the elimination of unnecessary, tiring movements or by the acquisition of more adaptive responses, such as "sleeping" and lever-pressing simultaneously. It was suggested that the adjustment-to-fatigue may be correlated with some physiological or biochemical adaptation caused by changes in the normal sleeping cycles or the stressful nature of the task. Further study of the adjustment-to-fatigue might be helpful in assessing problems of prolonged monitoring.

This is an adequate study, containing the average requirements for scientific methodology.

38

Caldwell, Lee S., and Evans, Wayne O., The Effect of an Analgesic Agent on Muscular Work Decrement, Ft. Knox, Ky., U.S. Army Med. Res. Lab., Rept. 538, DDC AD #283,275 (1962).

Abstract:

Previous work has shown that a correlation exists between the intensity of pain and the strength of contraction in a tonically contracted muscle. This study was conducted to determine if ischemic muscle pain and the decrement in contraction

strength are causally or merely correlationally related. Subjects were given an analgesic agent to reduce pain, under the assumption that, if the relationship was causal, the time for maintaining a strong contraction could be extended. The 14 subjects were male volunteers from the laboratory staff. The apparatus consisted of an adjustable seat and foot-rest which permitted all subjects to be placed in anatomically similar positions, and an isometric handle adjustable to produce similar arm positions for all subjects. Initially, each subject was given practice in the experimental procedure. "Peak strength" was determined by having the subject pull as hard as possible for 8 seconds, repeating the test several times until the subject's performance stabilized, and noting maximum force. In the endurance experiment a display amplifier was set to turn a green light on at 90 percent of the subject's maximum strength and the subject was told to keep the green light on as long as possible. The trial was terminated when the green light remained off for as long as three consecutive seconds. Each subject's strength and endurance was tested under seven conditions: a "no drug" or normal condition, four different doses of codeine sulfate (16, 32, 48, and 64 mg), a placebo condition using 100 mg of lactose, and an "active placebo" condition with 50 mg secobarbital (used as a test for a possible change in performance as a consequence of "feeling drugged"). The codeine was given up to its maximum effective dosage (64 mg), known to affect ischemic muscular pain. The conditions were counterbalanced to eliminate possible practice and cumulative fatigue effects. The experimental sessions were minimally 48 hours apart. The drugs and placebos were administered in identical capsules by a double blind procedure one hour before the tests. An eighth testing session was given under normal conditions as the last session to provide data for measures of test-retest reliability.

The results showed that the administration of the analgesic had no statistically significant effect on either the maximum strength or the endurance of an isometric muscular contraction. These data suggest that pain is not the limiting factor in the endurance of strong tonic muscular contractions, i.e., that relationship between pain and strength decrement is correlational, not causal. The correlation may result from a relationship to a third phenomenon—perhaps to the noxious metabolites which accumulate in the muscle during sustained contraction. It is also to be noted that when the subjects were asked why they were unable to maintain the required output, the most common report was that the pain was too intense. However, at the highest codeine dosage, most subjects reported a generalized weakness rather than pain as the reason.

This was an excellently designed, controlled, and interpreted experiment, with statistical analysis performed on the results.

39

Caldwell, Lee S., and Smith, Richard P., Subjective Estimation of Effort, Reserve, and Ischemic Pain, Fort Knox, Ky. US. Army Medical Research Laboratory, Report 730. DDC AD #655, 568 (1967).

Abstract:

Two studies were designed to compare the ratings of various subjective phenomena associated with strenuous physical performance, and to investigate the contributions of the scale itself to the ratings. The apparatus used in both experiments consisted of an adjustable hand dynamometer with strain gauges. A display meter with a pair of red and green lights provided the subject with a direct indication of his grip strength. A relay could be set to switch at any desired meter reading so that the green light was lit when the subject's output equaled the desired force, and the red lamp went on when his output fell below the desired level. Twelve male undergraduates aged 19 to 24 years were used in each study. The maximum grip strength of each subject was first determined from the mean of three, 5-second squeezes made 5 minutes apart, and this value was used in the experimental sessions to set equivalent loads for subjects differing in grip strength.

Experiment I: to compare ratings of effort and pain induced by an isometric muscle contraction maintained to the limit of endurance. Four randomly ordered experimental conditions consisted of rating pain and effort on a 5-point scale while holding a 30% and a 60% of maximum grip on the dynamometer. In each condition the subject was told to maintain the required grip force as long as possible and to report when the sensation was at each of 5 levels, with point one corresponding to threshold pain or 20 percent maximum effort, and point 5 corresponding to intolerable pain or maximum effort. Two identical trials separated by 30 minutes were given in each session, and the 4 sessions were at least a day apart. At the 60% load the function of time to produce the 5 intensities of pain and effort was essentially linear, while at the 30% load the time interval between successive levels tended to increase. Product-moment correlations between the contraction times at which a given intensity of experience occurred were significant for both the 60% load ($r = 0.80$, $p < 0.01$) and the 30% load ($r = 0.60$, $p < 0.05$).

Experiment II: to study the effect of scale interval size on judging both the effort required to sustain an isometric muscle contraction, and the reserve energy remaining for future use. The 4 experimental conditions consisted of scaling effort and reserve using both a 5- and a 10-point scale. On the 10-point scale the first point corresponded to 10% effort or 90% reserve, the second point to 20% effort or 80% reserve, etc. The subject was required to maintain a 50% maximum grip as long as possible while making the judgments, for 2 trials 30 minutes apart per session, for 4 sessions at least a day apart. It was found that the contraction times required to produce the various intensities of effort on the 5-point scale were significantly shorter (p 0.05) than those which produced the corresponding levels of reserve. No significant differences between the 2 types of judgment were revealed when the 10-point scale was used. Correlations between the scalings of effort and reserve were significant for both the 5- and the 10-point scale, and the correlations between the data obtained on the 5-point scale with those for the comparable points on the 10-point scale were also significant.

Though no overall difference was obtained between the pain and effort data, there was evidence that as the contraction time increased, or as the associated experiences became more intense, the pain and effort scales tended to diverge. The results of both studies indicate that subjects are capable of reliably scaling the subjective experiences produced by strenuous physical exertions.

40

Carlson, Loren D., Human Performance Under Different Thermal Loads, Brooks AFB, Texas, School of Aviation Medicine, Rept. 61–43, DDC AD #254, 374 (1961).

Abstract:

This study examined the physiologic effects of varying temperature and oxygen tension on the performance of a vigilance task. Nine subjects sat in an aircraft-type seat facing an 8-inch oscilloscope screen divided into quadrants or octants, which randomly presented a spot of light to be recognized by S. A loud bell occasionally interrupted the experiment, which was conducted for one, two, or three hours exposure to a temperature of 20, 25, 40, or 50° C. The physiologic strain of the environment was measured by recordings of rectal temperature, weight loss, pulse rate, arm and leg circulation, and respiratory rate. GSR was recorded to determine the basal skin resistance, the occurrence of nonspecific responses, and the magnitude and delay of specific responses. S was asked to assess his feeling state for anxiety, mood, and alertness on a 5-point scale. When a light appeared on the screen, the subject responded by pressing the button corresponding to the quadrant or octant in which the stimulus appeared. The rate of light presentation (2 bits/second to 8 bits/second), temperature, and quadrant or octant were randomly varied. An additional study was conducted using a fast quadrant vigilance test under lower oxygen tension (12% O_2). Subjects breathed air or the oxygen mixture through a Bennett face mask from an AF A–12 regulator connected to a cylinder of gas.

Results: (1) There were large individual differences which seemed to be related to phsycial fitness, as those who

were more active appeared to have higher limb blood flows and lower heart rates. (2) There was no effect on performance when the rate of stimulus presentation was low and temperature was varied from high to low. (3) With a higher rate of stimulus presentation, errors increased with a rise in temperature. (4) There appeared to be more errors when presenting stimulus in the octant arrangement. (5) GSR basal resistance and nonspecific responses increased with temperature rise. (6) The individual's judgment of his alertness had no relationship to his performance. (7) Blood flow, rectal temperature, water loss, and respiration rates all increased slightly with temperature increase, but this did not affect performance in the low input range. (8) There was evidence that low oxygen content caused performance decrements, but not to a significant level. This was attributed to the small sample size. There were also no signicant differences in blood flow or GSR response. (9) Although each individual's performance was consistent, the range of performance among the nine subjects was too great to permit definite analysis of the influence on vigilance. (10) The normal indices of stress—heart rate, sweat rate, and change in rectal temperature—did not reflect the circulatory responses as measured by blood flow. (11) It was concluded that vigilance was impaired in the hot environment at high levels of input.

This is an average study, but it is deficient in development and explanation. Very little statistical analysis is presented. Had the author used fewer dependent variables, he might have obtained better relationships between them and temperature and performance. It was also observed that the sample was too small to obtain significant results.

41

Carmichael, Leonard, et al., Some recent approaches to the experimental study of human fatigue. National Academy of Sciences, Proceedings, **35**, 691–696 (1949).

Abstract:

Studies of eye movements during long periods of continuous reading, military tasks such as stereoscopic ranging and eye-hand tracking during long periods without sleep, and of visual tasks under duress of sleep deprivation and protracted physical exercise are presented in brief. The general conclusions are that: (1) when the task required is not beyond the subject's normal ability, but when it is continued for a long time, the change in performance first noted is in apparently involuntary lapses in an otherwise continuous and effective performance. (2) As such continuous and monotonous tasks go on there seems to be a conflict between motivation, or the desire to continue, and level of performance. (3) When the subject sets himself to carry out a skilled performance after even a long period of interpolated physical work he is typically able to perform as well as in a rested state. (4) In general, however, as time without rest progresses, the number and duration of lapses increase until in a typical case sleep ensues. (5) The pattern of human fatigue as given in these experiments is thus seen to be one of periodic blocks or interruptions in performance of varying frequency and duration rather than the continuous decrement as shown in the work curves secured in the study of isolated muscle groups. Detail is insufficient to permit an evaluation of these studies.

42

Chiles, W. D., The Effects of Sleep Deprivation on Performance of a Complex Mental Task, Wright-Patterson AFB, Ohio, WADC TN 55–423, DDC AD 100691 (1955).

Abstract:

The effect of sleep deprivation upon performance was investigated, using a "complex mental task" intended to require very close attention and moderately difficult discriminations. The 6 subjects (volunteers from laboratory personnel, both male and female) were each deprived of 30 hours sleep. The task required the making of 200 discrete discriminations over a period of 25 minutes, comparing 20 small moving cards with each of 10 stationary cards with respect to the number of differences between them. Each card was marked with 6 symbols regularly located on the card, allowing zero to 6 possible differences between any two cards. The speed of movement of the cards required decisions at the rate of one per 6 seconds. There were 3 performance sessions: one at the beinning of the normal working day, a second 24 hours later (no sleep having been permitted in the meantime), and a third 6 hours after the second session. The performance of these subjects was compared with that of a control group of 5 subjects who performed the test 3 times but did so on 3 separate days, each session having been preceded by a presumably normal night's sleep. The 4 measures of performance were the numbers of (1) omitted, (2) correct, (3) incorrect, and (4) repeated comparions. Analysis was applied to data from the second and third sessions only, assuming performance on the first session would vary only accidentally, according to sampling differences between the two groups.

The statistical analysis revealed a significant difference between the two groups, i.e., the control group showed significantly more improvement from the second to the third sessions than did the group deprived of sleep. One of the subjects had considerable experience with the test prior to the experiment, and his performance was subsequently excluded from the general data. However, the superior performance of this subject suggested that learning might be altered by fatigue, but performance of the test—once learned—may be relatively unaffected. Similarly, the performance of one experimental subject, who in the first session had learned the task quickly, was superior to the other subjects; and this again led the author to conclude that learning, but not performance per se, was impeded by fatigue.

Although the statistical treatment in this study was good, there were many inadequacies in the author's methodology and analysis of results. To report as he did that "the control group showed significantly more improvement" was misleading, since significance was found in only 2 of 4 performance measures, and even then in only one or 2 of 3 statistical measures. The sample was inadequate: there were only 5 subjects in each group; the "learning versus performance" conclusion was made on the basis of 2 subjects' behavior; and a somewhat wide difference in performance between the 2 groups at the first session (when ideally they should be identical) showed a sampling variable which may have further complicated the data of so small a sample. It is difficult to understand why the performance change from the first to the second session was ignored entirely, when it seems an obvious and important measure of performance with 24 hours fatigue. Furthermore, the criterion for distinguishing "performance" from "learning" was not well formulated, using as it did identical measures of test behavior, and making it impossible to distinguish fatigued "performance" from slow "learning."

43

Chiles, W. Dean, Effects of High Temperatures on Performance of a Complex Mental Task, Wright-Patterson AFB, Ohio, WADC TR 58–323, DDC AD #155, 811 (1958).

Abstract:

This study was concerned with the effects of high temperature on performance on a complex mental task. Subjects were asked to compare each of 20 moving cards with ten stationary ones and report from zero to six differences between any two cards. Cards moved at a rate of one per 5.4 seconds; total task performance was 18 minutes. S was allowed 30 minutes to acclimatize to the test chamber before testing began, experienceing only one temperature condition on a day. Two groups of five men each were tested under dry/wet bulb temperature combinations of 85°/75°, 90°/80°, 110°/90°, 120°/90° F.; a third group of five was tested under 120°/105° F. There were no significant differences in performance under the various temperature conditions; also it was suggested that the 120°/105° F. condition was the upper temperature limit for task performance.

This study follows proper methodology but lacks adequate statistical analysis.

44

Chiles, W. Dean, Cleveland, John M., and Fox, Richard E., A Study of the Effects of Ionized Air on Behavior, Wright-Patterson Air Force Base, Ohio, Wright Air Development Division, WADD TR 60–598, DDC AD #252,099 (1960).

Abstract:

Three experiments were performed to investigate behavioral measures which have previously been shown to be sensitive to attitudinal changes of the sort alleged to be produced by ionized air. The test room measured about 13′ x 8½′, with an 8′ ceiling. Ventilation was provided by the building's furnace blower, and ions were generated by eight Wesix Ionaire ion generators and a Philco electrostatic ion generator and were measured by a Mark IV Wesix Ion Collector.

The five air-ionization conditions under which all tests were performed were called high positive (26,000/cm²/sec/volt positive ions of mobility > 0.007), medium positive (7,800 positive ions), zero (1,200 positive and 1,100 negative ions), medium negative (7,900 negative ions), and high negative (21,00 negative ions). Paid male college students served as subjects in all experiments.

In the first experiment, subjects were asked to compare each of 20 moving frames of film with 10 stationary frames, with a possibility of zero to six differences in the symbols they contained (this task was also used in Chiles 1955 and 1958). Fifteen subjects were divided into five equal groups, each of which performed under each of the five ionic concentrations in random order. Three subjects performed at the same time on three separate instruments, after a one-hour acclimatization period. Analyses of variance were performed on the omissions, number correct and number of errors; and only the group effect was significant ($p < 0.05$), and was significant for all three measures. The authors concluded that this was probably caused by the influence of one subject in one or more groups on the remaining subjects in that group. No straight-forward effect of ionized air was found on this complex mental task.

The second task was a modified Mackworth Three-Clock Test, with 100 double jumps occurring on all three clocks combined in a one-hour test. Again, 15 subjects were divided into five groups of three, each group performing in a different order under each condition. Subjects performed one at a time, with the next subject acclimatizing while one was taking the test. None of the F ratios was significant, and no effect of the ionized air was noted upon the vigilance behavior.

The third experiment involved measurements of attitudes, with five, four-subject groups, each experiencing the five ionic conditions in a different order. Each of the five test sessions took four hours, during which the group engaged in four identical one-hour cycles of 12-minute activity periods as follows: discussion of a freely-chosen topic, to permit opinion to arise; cooperation to determine the proper sequence in which to push four buttons to light completely a 14-lamp panel; cooperation in a manual dexterity test to get a ball to travel up a helical spiral; a free rest period; and an evaluation period, in which each subject evaluated his own feelings at the moment with an adjective check list and also checked his impressions of the attitudes of the other subjects. Five out of 100 F ratios for the check lists were significant at the 0.05 level or better, a number well within the limits of chance expectation. The authors concluded, therefore, that the various ion concentrations did not seem to affect the attitudes of subjects working as groups.

This is a good study, including quite high levels of ionization. Perhaps more investigation needs to be done of possible accumulative effects of ionization over longer periods than those reported here. The authors admit the possibility that the level of motivation of the subjects may have been sufficiently high to mask any effects of ionized air, in which case it would appear that instructions and indoctrination are more important than the effects of ions.

45

Christensen, E. Hohwu, Physiological Valuation of Work in Nykroppa Iron Works. in W. F. Floyd and A. T. Welford. eds., Symposium on Fatigue, chapt. 10, pp. 93–108, (H. K. Lewis & Company, London, 1953).

Abstract:

Pulse rate, O_2 consumption, calorie production, skin and rectal temperatures, and fluid discharge were measured for workers at various tasks in a not very modern iron foundry. This is a transcript of a symposium paper, and does not include a detailed discussion of the methodology used. The author notes that: "so-called easy work may be strenuous (1) if it is distributed over a few relatively weak groups of muscles; (2) if it is to a predominant extent of a static character; (3) if the working position is awkward; or (4) if the work is carried out at a high temperature."

The investigators report difficulty in attempting to measure the physical environment. Temperature and air speed (the latter with great uncertainty) could be measured, but heat radiation, of the utmost importance to the study, could not be determined quantitatively.

The greatest mean values for O_2 consumption (2.39 liters/minute) and for body heat production (11.6 cal/min) were obtained in open hearth slag removal. Wire bundling, involving the unassisted handling of 60 kg bundles of wire, and hand rolling in the heavy mill, produced the highest mean pulse rates—131 and 183 beats/min respectively. Maximum body temperatures of 39.5° C. and 39.1° C. were recorded during the operations of roughing (wire rod mill) and wire bundling.

Rankings of work tasks as to their relative physiological load was obtained by determining the average of the ranks for each task for each physiological measurement. The author cautions that this must not be done rigidly, as other factors, such as the effective work time per shift, must also be considered.

Three alternatives were considered for reducing the excessive body heat production: (1) reducing the rate of work, (2) alterating the work-to-rest ratio, and (3) modifying the environment. The third was regarded as being the most rational. Local cooling with an industrial blower lowered the temperature by 10° C., and alterations in clothing improved the micro-environment of the worker.

Because the full discussion of the methodology is not given in this paper, the study can be only provisionally rated as excellent. Other studies, such as those reported by Brouha, have reiterated the importance of physiological measurement.

46

Coates, D. B., The management of tiredness. Applied Therapy 6, 916–919 (Nov. 1964).

Abstract:

The article presents a schedule of what a doctor (MD) should do when a patient complains of tiredness. ". . . although fatigue may be part of a more specific syndrome when a specific diagnosis is made, fatigue is incidental to more dramatic symptoms in the overall picture." The doctor should first formulate the problem, involving the meaning of the symptom, related symptomatic behavior, predominant emotional response, and any significant relationships involved in the pattern. The patient must learn for himself to accept what is wrong with him and to plan his life. "A particular piece of advice to be avoided is the recommendation to get more rest." There is no discussion of any research base for the author's recommendations. A mediocre article.

47

Collins, J. B., and Pruen, B., Perception time and visual fatigue, Ergonomics 5 (4), 533–538 (1962).

Abstract:

A method of measuring visual fatigue was explored, using the exposure time ("perception time") needed to perceive Landolt rings accurately when successive rings were exposed at infinity and at the near point. The effect of a prolonged visual task upon this accomodation time was investigated, the task being a two-hour period of setting a vernier gauge. The task was performed under two different levels of illumination: 1 lm/ft² and 30 lm/ft.² The subjects were eight male students, 18 to 23 years old. They were initially trained (in approximately 5 or 6 training periods of 10 to 30 minutes over 2 or 3 days) until accommodation could take place with a presentation time of 0.12 second for the distant ring. The experiment began with a determination of the subject's perception time to identify accurately the orientation of the break in the two rings (far and near). The presentation time of the distant ring was kept constant at 0.12 second. and the presentation time of the near ring decreased step by step until the subject identified both rings correctly in 6 out of 10 pairs. The subject then performed the vernier gauge settings for 2 hours as rapidly and accurately as possible, after which his perception time with the Landolt rings was again measured. Subjects were asked to comment on their feelings of tiredness or freshness.

The results: (1) There was a significant increase ($p < 0.05$) in the average perception time required from before to after the visual task, considering the two levels of illumination together. (2) There was no significant difference in the changes in perception times between the two different levels of illumination. (3) Contrary to certain previous work, no average rise in variance of the settings was found during the two-hour period over which the task was performed. (4) Most subjects remarked on a feeling of slight tiredness after the period of working on the vernier gauge, with more complaints at lower illumination. There was no clear relationship between subjective feeling and objective score.

The experiment was methodologically well structured and reported, and there was adequate statistical analysis. The authors recommended further research with older subjects working at an industrial task known to require a high degree of visual effort and concentration. in order to demonstrate more clearly the value of the present method as an indicator of visual fatgiue. They reported a rejection of subjects for this experiment who failed during the initial training period to relax their accomodation to the 0.12 second presentation time for the distant ring, without stating how many (if any) subjects were thus rejected and thus leaving unclear this limitation of their sample. In light of the authors' recommendations above and previous studies which indicate older subjects accommodate longer. this initial rejection may be unwise.

48

Colquhoun, W. P., The Effect of a short rest-pause on inspection efficiency. Ergonomics **3**, 367–372 (1959).

Abstract:

Research was conducted on the efficiency of inspectors engaged in simple checking work, and on the effect of short rest-pauses on performance. The task was simple machine-paced checking work. designed to simulate industrial situations in which inspected articles are transported past examining stations on a conveyor belt, and in which the time-limit for detecting and rejecting faulty material is short. A large drum carrying one hundred 5¼" x ¾" metal strips equally spaced around its circumference, presented the flow of objects for inspection. The drum rotated at regular intervals, through one-hundredth of its diameter, presenting the strips sequentially at a viewing aperture. Six photographic prints of a disc. ¼" in diameter, were mounted on each strip. Of the 600 discs on the drum, 72 (12%) were faulty. in that they were marked by a small black spot. Faulty discs appeared on 68 strips, arranged in each of the six possible positions with equal frequency. The motor speed was set so that 50 strips (300 discs) were presented per minute, giving a viewing period for each strip of approximately one second. They subject's task was to inspect each set of six discs as it appeared and to press the key under any disc which carried a spot, before the drum removed the set from view and replaced it with another. The performance measure was the number of response failures. Test sessions lasted one hour, during which the entire sequence of 100 strips was displayed 30 times. The subjects were 32 young naval ratings. A five-minute practice period was given, after which the subject was told to carry on inspecting for "about an hour." Half the subjects were informed they would have a break "half-way." These subjects were given a rest of five minutes after 30 minutes of testing.

The results showed that when the work was uninterrupted for a period of one hour, efficiency. although high on the average, declined markedly after about 30 minutes. When a rest-pause of five minutes was inserted at this point, performance was maintained at its initial level throughout the hour. Statistical analysis of scores for the first half-hour showed no significant difference between the "rest" and "no-rest" groups. It cannot be said. therefore that knowledge of a forthcoming rest-pause had any effect on performance during the first half-hour. The difference between the two groups in the last half-hour. however. was significant at $p < 0.05$. indicating the rest-pause had a genuine effect on efficiency in the period that followed it. The differences in individual checking efficiency were found to be unrelated either to intelligence as measured by Heim's test A.H.4, or to temperament as indicated by scores on Part I (emotional instability) and Part II (unsociability of the Heron test. The average level of efficiency was much higher, in both "rest" and "no-rest" groups, than the usual levels observed in "vigilance" experiments. Previous research has found that detection efficiency in a vigilance task is related to the frequency with which the "wanted" signals are presented. and it was speculated that the high rate of signal presentation in this study (68 out of 100 strips were faulty) was in part responsible for the superior performance. The behavior of the subjects and their personal reports indicated that fatigue and boredom were more prevalent in the group without rest than in the rested group.

This was a well designed and interpreted experiment, precisely reported, employing good statistical techniques. The author suggested that in further research the viewing time for each strip should be increased, since the one-second response required in this study prevented a distinction between a detection failure and a slow reaction.

49

Consolazio, C. Frank. et al., Physiological and Biochemical Evaluation of Potential Anti-fatigue Drugs. I. The Effects of Aspartic Acid Salts (Mg and K) on the Performance of Men, Denver, Army Medical Research and Nutrition Lab., Rept. #273, DDC AD #400, 720 (1963).

Abstract:

This study was designed to investigate the use of magnesium and potassium salts of aspartic acid (Spartase. one of the so-called antifatigue agents), as a possible means of increasing endurance and prolonging the onset of fatigue in humans. The performance of 12 men was measured during a nine week study which consisted of: (a) two weeks of a preliminary control period designed for training: (b) five weeks of therapy during which six of the men received placebos and six received 2 gm of magnesium and potassium salts of aspartic acid twice daily; and (c) two weeks of control or recovery.

There was no significant difference in metabolic rate and respiratory quotients between the control or Spartase supplemented groups during moderate exercise (a 30-minute brisk walk on a motor-driven treadmill at 4.0 mph on a 3.5% grade each day) and the recovery period after moderate exericise. Differences in other factors such as maximum breathing capacity. vital capacity, etc., were also non-significant. A significant difference was observed between the groups during the last week of therapy in breath holding time. This was also true for the neuromuscular excitability time values after the exhausting run, which were significantly different only during the 4th week of therapy and not during the 5th week. It is questionable whether these two differences could be attributed to Spartase therapy since these differences were also observed two weeks after the discontinuance of therapy. Under the stresses imposed in this study there seemed to be no convincing evidence of the beneficial effects of Spartase therapy.

This is a well-executed study, containing good development and discussion of the problem. Statistical treatment consisted principally of the *t*-test applied to mean or individual differences as appropriate, with evaluations at the 5% level of significance.

(Authors' abstract, modified)

50

Daniels, Farrington, Jr., Vanderbie. Jan H., and Winsmann. Fred R.. Energy Cost of Treadmill Walking Compared to Road Walking, Lawrence. Mass.. Natick QM Research and Development Laboratory, Environmental Protection Division, Report No. 220, DDC AD #20,049 (1953).

Abstract:

The metabolic rates of eight subjects carrying a 46-pound load at 3½ mph on a treadmill were compared with the same group carrying the same load and wearing the same clothing while walking at the same speed over a level, asphalt road out of doors. An additional group of four subjects was compared while wearing eight-pound nylon vest armor (without a pack load) on the treadmill and on a cinder track. The subjects ranged in age from 20 to 30 years, in weight from 51 to 80 kg. in height from 167 to 179 cm, in body fat from 1.2% to 14.7%, and in surface area from 1.54 to 1.92 m^2. Clothing consisted in all cases of the Army cotton fatigue uniform with leather combat boots. The metabolic rate during walking on the treadmill was measured with a closed system Tissot spirometer, and the studies conducted in the field were done with Douglas Bags with the air analyzed by the Haldane method. A systematic comparison of these two procedures made with two subjects walking on the treadmill indicated no statistically significant systematic difference between them. The treadmill studies were carried out at a room temperature of 66° F., the outdoor walking on a macadam road with air temperatures from 25° to 50° F., and the cinder track walking in air temperatures of 64° and 70° F.

Results: (1) Comparison of walking with 46-pound load at 3½ mph on treadmill and macadam road: (a) Mean metabolic rate (in cm^3 0_2/min) on the road was 1426.9, and on the treadmill it was 1313.0. A *t*-test indicated that the difference (of 5%) was significant beyond the 0.01 level. (b) The mean metabolic rates expressed in cal/m^2/hr. were 234.6 for the road walking and 215.5 for the treadmill. The percentage difference was 8.9, and the *t*-test was significant beyond the 0.01 level. (c) In terms of cm^3 of oxygen per horizontal kilogrammeter (man + clothing + load moved forward one meter), the mean metabolic rate was 0.1695 on the road and 0.1557 on the treadmill. The difference between the means was 8.9, and the *t*-test was significant beyond 0.02.

(2) Comparison of walking while wearing eight-pound nylon vest armor on a treadmill and on a cinder track: (a) Mean metabolic rates in cm^3 0_2/min were 1219.0 on the track and 1108.2 on the treadmill. The percentage difference between the two means was 10.0, but the *t*-test was not significant. (b) The mean metabolic rates in cal/m^2/hr were 203.5 for the track walking and 184.8 for the treadmill. There was a difference of 10.1 per cent between these two means, and again the *t*-test was not significant.

The authors concluded that subjects carrying loads over an asphalt road and a cinder track at 3½ mph have an average energy expenditure nine to ten per cent greater than they do when carrying the same load on a treadmill with a belt speed of 3½ mph. There is, in the opinion of the authors, a distinct difference in the body mechanics of treadmill walking and of walking under normal conditions.

It appears that environmental temperature was not controlled for adequately between the treadmill sessions (at 66° F.) and the walking on asphalt (at 25° to 50° F.). It might be expected that. had the outdoor temperature been closer to that of the indoor (i.e., higher), the metabolic cost of walking outdoors would have been lower (i.e., closer to the rates on the treadmill). The walking on the cinder track, done in an air temperature comparable to that of the treadmill room, led to a percentage increase of metabolic rate over that on the treadmill comparable to that produced by walking on the road. Assuming the cinder track surface to be looser and more irregular than that of the road, one might have expected the metabolic rate increase to have been greater for the cinder track. It may be that the temperature differences increased the apparent difference between walking on a treadmill and normal outdoor walking. Further experimentation, controlling more closely for temperature (and perhaps also for air movement, by doing all walking either indoors or outdoors), and using more subjects, is recommended.

51

Davenport, E. W., An Investigation of Fatigue in ASW Helicopter Crews, USN Electronics Lab., San Diego, Calif., DDC AD #76250 (1955).

Abstract:

Twelve men in an ASW helicopter unit were divided into four crews and served as subjects in a study designed to investigate objectively and subjectively the extent to which fatigue affected performance. A further objective was the determination of measures which would be useful in predicting performance, and hence be helpful in providing information concerning flight duration, rest periods, relief crews and other aspects of operation. Each "crew" consisted of a pilot. sonar operator, and a control. The study was performed over a five-day period and included three 2½-hour flights and three 1-hour testing periods each day. The measures taken were: (1) inflight measures—drift indicator. tranducer tilt indicator. sonar. and communication records; (2) postflight measures—speed and coordination tests, steadiness test. tapping-rate test. CCF, and hearing threshold and masked hearing threshold tests; (3) subjective measures—pilot, sonar. and safety pilot questionnaires and an interview with the controls on the last day of testing.

The results indicated that there were no significant differences in any of the inflight or postflight measures. There was, however, evidence of temporary hearing loss on the part of the sonar operators immediately after flight. The questionnaire results indicated that pilots and sonar men felt that their performance had not been interferred with although they were fatigued. This was supported by the safety pilots, who reported noticing symptoms of fatigue, but no decrements in pilot performance. The controlled interview indicated that the principal factors affecting fatigue for the sonar crew were psychological factors such as monotony, boredom, anxiety, and frustrations. Medical examinations indicated that the experimental subjects showed symptoms of fatigue that were more acute than those resulting in non-test conditions.

This was a well-structured study, but it contains very little statistical analysis. Criticisms and recommendations by the author are helpful and indicate where much future research is needed.

52

Davis. S. W., and Taylor, J. G., Stress in Infantry Combat, Chevy Chase, Md., The Johns Hopkins University, Operations Research Office, Tech. Memo. ORO-T-295 (1954).

Abstract:

This is a working paper designed to determine the extent to which combat stress affects the tactical usefulness of infantrymen in infantry units. Twelve psychological measures, including judgment. memory. abstraction, and sensitivity of neural mechanisms; and twenty-seven physiological measures to assess the effect of combat stress on the function of the adrenal gland, (eg., eosinophil count, cholesterol. sodium-potassium ratio, ACTH test) were made. The subjects consisted of two experimental groups, one in short, intensive combat (attacking company) and the other in prolonged, less intensive combat (defending company); and a control of 24 non-combat men. Testing was over 26 days and consisted of pre- and post-combat measures for attacking and defending companies and pre-combat measures for the control group. The study was conducted in actual combat situations in Korea.

Results: (1) The control group experienced the normal physiological reactions of the combat infantrymen by virtue of being just behind the main line of resistance. (2) There were characteristic physiologic reactions for the combat groups. The attacking company experienced a high degree of adrenal responsiveness, increased protein destruction, and a shift in body salt balance. The defending company experienced effects in the opposite direction. (3) Recovery time was longer in proportion to the duration of the stress and more costly for the attacking company. (4) The attacking company was characterized by initial or adaptive stress reactions; the defending company by secondary or resistance stress reactions. (5) The initial period of combat was more costly than continuing past the initial period in that recovery time was longer in proportion to the duration of the stress.

This is an extremely comprehensive and detailed report. Thorough treatment in all areas is given.

53

DeVries, H. A., and Klafs, C. E., Ergogenic effects of breathing artificially ionized air, Journal of Sports Medicine and Physical Fitness, **5** (1), 7–12 (1965).

Abstract:

To test the hypothesis that breathing negatively ionized air would result in improved physical performance, 45 college age students (21 male, 24 female) were tested for endurance by stepping onto a 20-inch bench at a cadence of 36 steps per minute. Each individual served as his own control, and each group was divided so that each member could serve as both subject and observer. The test score was the time in seconds that a subject was able to continue at the prescribed cadence. Ion-O-Matic Air Improvers made by Tubin Electronics generated from 225,000 to 450,000 ions per cc of air per second at a 12" distance. Four stations were set up in different rooms: negatively ionized, positively ionized, placebo (ion machines present, but circulating only the normal room atmosphere), and control (no machines present). Each subject was exposed once at each station for 15 minutes, followed immediately by an exercise bout, with a mean time of 72 hours between subsequent tests. During exposure (seated 12–18" from a machine at head height) or as control, subjects were given problems in kinesiology to calculate, to relieve possible psychological factors.

Although all subjects had practiced the stepping exercise twice before testing, this had not resulted in plateau performance, for a significant ($p \leq 0.05$) improvement occurred between the means of the first and last test, regardless of the order of test conditions. Analysis of variance by Lindquist's type II mixed design again found an order effect significant beyond 0.01. The treatment effect, however, was not significant at 0.05, nor was the interaction of order and treatment. The performance data of the female subjects appeared to follow the direction of the working hypothesis, but neither treatment nor interaction F's were significant at 0.05. A majority of the subjects, when asked which treatment room made them feel best, indicated the room with negative ionization; and a number of subjects reported headaches and feelings of dullness in the positive ionization room.

The authors recommend that further experimentation be done into (a) effects of varying intensity and duration of ionization, (b) effects of long-term exposure, (c) effects upon individual physiological parameters, and (d) effects upon other measures of human performance. It is realized that the step test to the fatigue point is not a precise measurement and does not always correlate well with other measures of fatigue.

54

Dill, David B., Fatigue: A case history, Journal of the American Geriatrics Society, **9** (12), 1025–1031 (1961).

Abstract:

This is a well-reported case history of the author's cardiovascular responses to exercise when in his late 60's, and 20 to 34 years earlier. Experiments included exhausting work on the treadmill and the bicycle ergometer. Dill's maximum heart rate in exercise on a bicycle ergometer declined from 172 beats a minute at age 37 to 162 at age 50, 160 at 66, and 150 at 70. Exhausting work on the bicycle ergometer at age 41 ended at 15 minutes with a pulse rate of about 165 and oxygen consumption of 2.75 litres per minute; while at age 70, work lasted only 7 minutes, with a pulse of 150 and oxygen consumption of 1.96 liters per minute. In each of these two experiments the heart rate increased to 130 during the first minute, and then diverged. At age 41, Dill's maximum oxygen consumption while walking a treadmill (3.34 liters per minute) was 22% greater than on the ergometer, and at age 70, the treadmill value (2.30 liters per minute) was 11% greater than the ergometer value.

Dill has been a subject on the Balke treadmill test, involving walking at 3.36 mph on a treadmill whose bed is raised 1% each minute. At age 66, when he weighed 80.5 kg, Dill became exhausted at 15 minutes, with a final heart rate of 160. After dieting to 72 kg, at age 67, Dill's limit was 17 minutes, and at age 68 it was 16 minutes. The heart rates up to the fifteenth minute were lower by from 10 to 20 beats per minute in the latter 2 cases. During the last 2 minutes of work at age 67 the pulse gradually rose from 150 to 160, and during the exercise at age 68, there was a sudden rise during the last minute from 145 to 160. At age 70, Dill was able to walk for 16 minutes; however, the maximal heart rate (150) was less and his oxygen consumption (2.3 liters per minute) was in contrast to 2.75 liters at age 66, 2.6 liters at 67, and 2.5 liters at 68. The blood lactic acid concentration at the end of the treadmill test at age 70 was 34 mg per 100 ml, corresponding to a lactacid oxygen debt of about 2 liters. Blood pressure responses were nearly identical at ages 67 and 68—the systolic rose gradually from about 135 mm Hg at 3 minutes to about 150 mm at 15 minutes, after which it rose rapidly to about 175 mm. The diastolic pressure was unchanged until the fourteenth minute, when a rise occurred.

55

Domanski, Thaddeus J., Physiological Recognition of Strain in Flying Personnel, Eosinopenia in F–85 Combat Operations, Randolph AFB, Texas, School of Aviation Medicine, DDC AD #20,375 (1953).

Abstract:

Twenty-one pilots engaged in F–85 combat missions in Korea were studied to determine if there existed a relationship between eosinopenia and the quality of combat performance of the pilot. Five subjects were omitted in the final analysis as they did not complete the testing period for various reasons. The remaining 16 pilots were divided into two groups—Group A consisting of the average, better than average, and superior combat pilots; Group B, of the weak and very weak combat pilots. Eosinophil counts were taken before and after 2-hour combat missions were flown. The missions were classified as routine combat missions (no air-to-air engagements) and difficult combat missions (air-to-air contact). Eosinopenia was defined as at least a 50% decrease in the circulating eosinophil count.

The findings indicated that, (1) In the case of the routine combat missions, eosinopenia was significantly associated with Group B pilots ($p < 0.01$). (2) The absence of eosinopenia following a difficult combat mission was confined to Group A pilots. (3) No critical relationship was found between altitude and eosinopenia.

This is a very detailed study with discussions of each subject's performance, and average statistical treatment. It contains recommendations by the author as to problems needing further research—when eosinophil counts should be taken, what should determine eosinopenia, and the use of eosinophil counts in rating pilots.

56

Domanski, T. J., et al. Physiological Relationships in Human Stress Response: I. Eosinophil Response to Muscular Activity, Randolph AFB, Texas, USAF School of Aviation Medicine, Project 21–32–025, Report No. 1, ATI 118, 123 (1951).

Abstract:

Nine healthy males, predominantly Air Force personnel, and ranging in age from 19 to 37 years, walked on a treadmill at a constant velocity of 3.5 mph to investigate the response of the eosinophil level to muscular exercise. All subjects walked (a) for 12 minutes, or (b) until reaching a pulse rate of 180 bpm. Six of the subjects also walked to the point of subjective exhaustion. The treadmill bed was level for the first minute of each exercise, and was raised two per cent at the end of the first minute of walking and one per cent at the end of each succeeding minute. The subjects wore athletic trunks and tennis shoes, and performed in an air-conditioned room. Subjects made one run per day on one to three not necessarily successive days. Pulse rates were taken before exercise and during the latter 30 seconds of each minute during the exercise and recovery periods. Eosinophil counts (taken from a finger puncture, and analyzed using the Randolph technique) were taken at four different times during each exercise day, a base-line value being followed by counts taken at one, two, and three

hours post exercise and at corresponding times on one or two control days per subject. The percent change in eosinophils relative to the base-line count of a given day was calculated for each of the subsequent counts made on the same day, each of the latter values having assigned to it a positive or a negative sign depending on a rise or fall in eosinophils relative to the base-line count. The percent values were algebraically added, then divided by the number of counts made subsequent to the base-line count to yield a quotient the authors call the *eosinophil profile.*

Treadmill exercise was not found to be invariably associated with a negative eosinophil profile. Furthermore, the magnitude of the eosinophil response was different for different individuals. Three subjects, whose profile was −17 or lower for the 12-minute test, showed relatively little additional drop in profile, or showed an increase, when exercised until the attainment of a pulse rate of 180 bpm. Three other subjects, with eosinophil profiles of −3 or above for the 12-minute test, produced relatively large decreases in profile when exercised to a pulse rate of 180. One subject (an athlete experienced in track events) gave a positive profile in both tests, and a profile change of zero when he walked to exhaustion. The following generalizations were made: (a) the rise in pulse rate followed a similar pattern in all three tests; (b) an increase in the duration of the treadmill exercise accentuated the stated similarity, with pulse rate data for the exhaustion test being a linear extension of the 180 pulse rate test findings; and (c) pulse rate recoveries following exercise were related to the extent of the antecedent displacement of the resting pulse rate.

Results were presented for each individual, but were nowhere reduced and analyzed for the group as a whole. Although the eosinophil profiles were so variable as to possibly make group discussion meaningless, such data as pulse rate curves and exercise times to 180 pulse rate or exhaustion could have been reduced to group means to allow easier comparison with the results of other studies. The design of the experiment in general—especially the analysis of eosinophil levels and the controlling for individual diurnal variations in eosinophil level—is excellent.

57

Drew, G. C., An Experimental Study of Mental Fatigue. London, Flying Personnel Research Committee, DDC AD # 237 773 (1960).

Abstract:

To accurately assess the symptoms and causes of fatigue, 140 pilots served as subjects and were placed in an old Spitfire cockpit with fully intact and working controls that were monitored electronically from another room. The subjects were able to simulate the feeling of flight and many forgot that they were not actually in the air during the experiment. Full instruction and explanation of how to manipulate the cockpit with a trial period of about 30 minutes during which the experimenter corrected mistakes they were making, preceded the test period. There were four maneuvers to be performed: (1) a dive of 3500 feet at a rate of 3500 ft/min· (2) a Rate I turn to the right through 210°; (3) a climb of 3500 feet; (4) a Rate I turn to the left through 210°. Whenever a red light was on, these maneuvers were performed in the following order: #1, 1'30" after the signal; #2 after 3'45"; #3 after 7'30", and #4 after 10'. If the red light continued, the ten minute sequence was started again, and continued until a white light came on, which indicated that the pilot should fly straight and level. This procedure lasted for two hours (including the practice period) in the following arrangement: 1 unit of maneuvers, level flying, 2 units of maneuvers, landing and finish. All maneuvers were timed in order to later assess effects of fatigue on performance. A football bladder was placed under the pilot's seat and inflated or deflated when the subject was instructed to dive or climb. This was done at three different times for three different groups: at the beginning, middle, or end of the test. Also during these periods, at the sound of a buzzer, the pilots would study a set of instructions which indicated the same course they had already been on but in different terms, and were directed to work out a new schedule. When the buzzer sounded again they had to use this new schedule for flying. None of the pilots in this phase of the experiment realized that they were the same instructions as before.

Results: (1) All pilots reported subjective mental fatigue at the end of the two hours. (2) Performance deteriorated with increased mental fatigue on all measures (e.g., response time, accuracy). (3) The greatest performance decrements occurred in the last two maneuvers before landing and finish. (4) Timing of maneuvers rather than accuracy decreased with fatigue. (5) Fatigued pilots tended to split a complicated task into its component parts, rather than treat the system as a whole, and thus caused serious errors. (6) Irritability increased with fatigue. (7) Temperature, pressure, signal lights, etc., tended to be overlooked when fatigue increased, resulting in errors. (8) Change in seat pressure caused performance improvement in both tired and fresh pilots. (9) It was concluded that when fatigued, pilots exhibit: (a) great irritability; (b) increase in careless errors; (c) have a great awareness of physical discomfort; (d) tend to ignore side instruments; (e) do not exhibit reduced accuracy when the course is changed. (10) The number of flying hours, I.Q., initial performance scores, and rate of fatigue were related, but there was not enough evidence to indicate in what way.

This would probably be at best an average study if the report were more organized! The author rambles, which makes it difficult to objectively assess his work. There are virtually no statistics presented at all, merely graphic representations of mean performance rates of the groups.

58

DuBois, Eugene F., An attempt to classify occupations in ten task groups according to physical exertion or according to the amount of physical exertion demanded, Proceedings of the American Philosophical Society, **104** (1), 111, 112 (1960).

Abstract:

While investigating the effects of age on various physiological tests and measures of physical fitness, the author noted large individual differences, apparently depending not so much upon age as on occupation and athletic training. Therefore, an effort was made to classify occupations into ten grades by degree of physical fitness, so that comparisons could be made within each group to determine the effect of age. Discussion of the classification forms the body of this article. It is not clear as to what degree this classification is based on DuBois' data or on the literature which he cites. Two criteria were used to estimate the grade of physical fitness: (1) The estimation of the total caloric expenditure per day, which has usually been obtained indirectly by measuring the food intake of people engaged in these different occupations. (2) The number of calories expended per minute in the peak tasks involved in the various occupations.

The ten grades of physical fitness are presented with their respective levels of energy expenditure in graphic form, from which has been abstracted the following:

(1) Bed-ridden. 1800 calories/day; 1–2 calories/minute.
(3) Patient confined to home. 1900 cal/day; 2–3 cal/min.
(3) Semi-invalid—a few hours of easy work. 2000 cal/day; 4 cal/min.
(4) Very light work—clerical, watchman. 2100 cal/day; 5 cal/min.
(5) Light work—clerk in a store, executive. 2300 cal/day; 6 cal/min.
(6) Moderately hard work—salesman, physician, light factory work. 2600 cal/day; 7 cal/min.
(7) Hard work—farmer, mason, carpenter. 2500–4000 cal/day; 8 cal/min.
(8) Hard labor—pick and shovel, lumberman. 3000–5000 cal/day; 9 cal/min.
(9) Athletes in training. 3300–5100 cal/day; 13 cal/min.
(10) Champion athletes in training. 3500–5200 cal/day; 17 cal/min.

59

Ekey, David C., and Hall, Thomas J., Operational methodology for evaluating physiological costs, The Journal of Industrial Engineering 12 (4), 243–252 (1961).

Abstract:

Ten male college students were selected at random from a stratified population (a Georgia Tech fraternity group of sixty students) to perform standard tasks on a bicycle ergometer and a vertical torsion bar ergometer. Five subjects were randomly assigned to the torsion bar task and five to the cycling task. The cycling task utilized a constant brake load and the subject was required to maintain, by visual observation, tachometer readings of 18 rpm (slow speed), and 36 rpm (high speed). Effective energy outputs at these speeds (considered to be strenuous exercise) were calculated to be 0.064 horsepower and 0.128 horsepower, respectively. The torsion bar task utilized a constant torque load and the subject was required to maintain, by visual observation of a metronome, uniform stroke rates of 50 per minute and 100 per minute. Effective energy outputs at these rates (mild exercise) were 0.023 hp and 0.046 hp, respectively.

Each subject performed at both task levels, on different days. Performance consisted of five three-minute work periods interspersed by six three-minute rest periods. Heart rate (recorded on a cardiotachometer by electrodes placed on the chest) and heart sound (picked up by a microphone placed over the apex of the heart) were recorded continuously for the 33-minute test period. Galvanic skin response was recorded at the beginning and end of all work and rest periods, and blood pressure components (by a cuff taped to the upper left arm) only at the end of each work period. Other variables—room temperature, relative humidity, time of day, and subject's height, weight, age, weight-to-height ratio, and relative physical fitness—were recorded, but were not considered in the analysis of the results. After the five subjects had completed two levels for a given task, the experiment was replicated with the order of task performance again randomized.

Two subjects became exhausted because of excessive heat and were unable to complete the replication of high speed strenuous exercise. Analysis of variance indicated that the time period effect was the most significant source of variation in all phases of the experiment. It was found to be significant at the 0.01 level for all of the dependent variables except for blood pressure at mild exercise. The task level effect and operator effect were significant over time, and the task level consistently interacted with time at various degrees of sensitivity among the dependent variables and tasks. The operator effect was consistent to a lesser degree. Heart rate was the most operational dependent variable, being a very sensitive indicator of work at all task levels. Heart sound data for strenuous work were not usuable because of extraneous sound artifacts, and heart sound was not found to be a homogeneous predictor among the five subjects doing mild exercise. No significant variation was found among subjects for pulse pressure (the difference between systolic and diastolic blood pressures), indicating that pulse pressure may be a definitive work measurement tool. GSR increased linearly with work over time at all task levels, while the trend of all other dependent variables was quadratic over time. All rest curves, except GSR, exhibited a decreasing rate of recovery over work time. The GSR rest functions were monotonically increasing through all task cycles.

Too few subjects were run on too few trials in this study. Recording heart sounds and calculating pulse pressures show imagination, and achieved a partial success. The indicated effectiveness of pulse pressure as a work cost measure needs to be validated, as the authors themselves suggest, for larger groups and over longer time periods.

60

Evans, Wayne O., A Titration Schedule on a Treadmill. Ft. Knox, Ky., U.S. Army Medical Research Lab., Rept. #525, DDC AD #269,534 (1961).

Abstract:

Treadmills have often been used to induce fatigue in subjects, but they have had no way of assessing the continuous changes in performance capability as a function of continued exertion. It was felt that by using a titration type of schedule which would enable the subject to monitor the speed of the treadmill, these changes in performance could be measured. Three male subjects (age 24–30), in rather poor physical condition, were instructed to walk on a treadmill and monitor the speed by means of a Graham drive unit (2 ft/min/sec). Treadmill speed was graphically reproduced by means of an Esterline-Angus recorder. There were three trials in all, the subjects being instructed to maintain the initial walking speed as long as possible and then slow it down. When walking velocity reached 60% of the initial rate in the first trial and 70% in the second and third, the trial was concluded. Sessions were at least 48 hours apart.

It was concluded that this method provided a direct and objective measurement of the performance capability of a subject. It was suggested that this method may aid in assessing other factors associated with fatigue and performance decrement, such as motivation and physical fitness.

The author presents no statistical analyses of results, and his sample is very small. He also does not present the rationale for some of his actions: for example, why he used subjects that were in poor physical condition. This report is a preliminary study to determine the possible worth of the proposed method of measurement. Evans utilized this method later (Evans, 1962) in which a more disciplined study was conducted. The findings of this later study confirmed his hypothesis that this is a valid and reliable measurement of performance decrement.

61

Evans, Wayne O., The Effect of Treadmill Grade on Performance Decrement Using A Titration Schedule, Fort Knox, Ky., U.S. Army Medical Research Lab. Rept. #535, DDC AD #275,974 (1962).

Abstract:

Ten male Army volunteers (ages 20–36) served as subjects in an experiment designed to measure performance decrement due to submaximal exercise using a titration schedule on a treadmill. The apparatus consisted of a power driven treadmill, a Graham reversible drive system, a tachometer-generator, and an Esterline-Angus ink recorder. A spring-held switch, controlled by the subject, reversed the direction of action of the Graham drive system which was connected to the velocity control of the treadmill so that when the subject-controlled switch was released, the treadmill belt accelerated at a rate of 2 ft/min/sec. A depression of the switch caused the belt of the treadmill to decelerate at the same rate. The subject had to continually monitor his velocity and adjust the velocity of the treadmill by alternately depressing and releasing the switch. A recorder was attached to the tachometer-generator which was in direct contact with the drive wheel of the treadmill, and continually graphed the treadmill velocity. Each subject was given a 5 minute practice period on the treadmill under conditions of constant and changing velocity. The experiment consisted of three sessions on treadmill grades of 5%, 10%, and 20%, with 24 hours between each session, in a room temperature of 80° F. Subjects were instructed to walk at a fast but confortable pace until told to stop. Initial treadmill velocity was always 265 ft per min. Sessions were terminated when the subject's walking rate fell to a value 20% below his initial walking rate, which was defined as the average value in feet per minute of the subject's first four maximum upward excursions of the recorder pen (peaks).

Measures included: peaks (maximum points of upward pen excursion), troughs (maximum points of downward per excursion), peak to trough differences, and the performance envelope. Using the best linear fit to peak responses, it was found that: (1) grade of slope was related to fatigue; (2) ordinal intercept and total walking time varied significantly ($p < 0.001$; $p < 0.01$) as a function of grade; (3) slope constant did not vary significantly with grade; (4) no significant changes in the performance of the "tracking behavior" were found which could be regularly related to either change in grade or to continued performance of the exercise task. It was

concluded that submaximal exertion tasks were not as satisfactory as maximal exertion tasks to measure fatigue. It does, however, produce indices which are related to fatigue.

This was an average study. Proper methodology and development were used. Statistical treatment was thorough, including the methods of least squares of linear fit, Pearson Product-moment correlatin coefficients, and analysis of variance.

62

Evans, Wayne O. and Caldwell, Lee S., The Effects of the Potassium and Magnesium Salts of Dl-Aspartic Acid on Human Fatigue and Recovery, Ft. Knox, Ky., Army Medical Research Lab., AD #291,733 (1962).

Abstract:

A physical task using an arm dynamometer was utilized to test the effects of magnesium and potassium salts of dl-aspartic acid on the strength and endurance of human subjects. Five subjects were given two pills a day for four days prior to testing. The pills were either the aspartates or placebos. Each S was tested four times with each, once a week for eight weeks. The task consisted of a ball-mounted isometric handle with strain gage attachments which S had to pull and maintain a constant tension, rest, and then repeat until the experimeter ended the session. There was no significant difference in performance with the aspartates or with the placebos, although the Ss could subjectively discern between the two, and reported feeling better when using the aspartates.

This study contains little statistical treatment. The population used was too small to attribute much significance to the reported findings.

63

Fischer, R., et al., Problems of hygiene of higher nervous activity in telephone operators and a physiological method of studying work load to the CNS, Activitas Nervosa Superior (Prague) **3** (1), 62–70 (1961).

Abstract:

The object of this study was to determine if the flicker fusion frequency (FFF) was a sensitive measure of mental fatigue. Twenty-five female telephone operators on the morning, afternoon and evening shifts, were instructed to view a flickering neon tube (which rate of flicker rose at a rate of ⅓ cycles per second) and to identify the critical flicker fusion frequency. There were fifteen trials, taking place the last ten minutes of each hour of work. Great individual differences existed in the degree of influence work had on the FFF. Those Ss who reported subjective fatigue had depressed FFF scores. An increase in FFF scores was noted after a 30-minute break for all subjects. It was concluded that the FFF can be considered a relatively good group test to indicate the work load to the CNS.

This is a good study and contains extensive statistical analysis, with all significant findings at the 0.01 or 0.05 level.

64

Flying Personnel Research Committee, A Preliminary Study of Flight Deck Work Loads in Civil Air Transport Aircraft, Farnborough, England. The Ministry of Aviation and the Royal Air Force, FPRC 1240, DDC AD #476,902 (1965).

Abstract:

Sixteen scheduled transatlantic flights were flown in BOAC Boeing 707 jet aircraft, each with an observer and one of four volunteer subjects—the aircraft captain. Four of the trips were from London to New York and back to London, and four from London to Bermuda and return. Overnight stops were made at the western terminus in each case. Two pilots (one medically qualified) and two medically qualified physiologists served as observers, each assigned to a particular subject. The observer traveled in the jump seat immediately behind the captain, kept a written account of events as they occurred, and logged environmental conditions—temperature, humidity, and cabin altitude. A continuous recording of the captain's heart was also taken, and a spoken commentary on the flight and the captain's activities was given by the observer and recorded on the same tape. The subject's urine was collected from 2200 hours on the day before a flight until about 0800 the morning after, and also on non-flight-activity control days. In addition, the subject filled out a subjective fatigue check list (modified from Pearson and Byars, 1956) as soon as possible after landing. On half of the flights, respiratory end-tidal samples were taken from the subjects on the runway soon after touch down.

All subjects showed a rise in heart rate on take-off and a generally greater (sometimes above 140 bpm) and more prolonged rise during descent and landing. Throughout the flight, recorded peaks of faster heart rate were usually synchronous with identifiable periods of greater pilot activity, such as position reporting, eating breakfast, or encountering turbulence. The cabin temperature was generally fairly constant, between 20 and 23° C.; but the humidity usually fell during the flight, sometimes to as low as 10%. Cabin pressure was generally kept between 5,000 and 7,000 feet during the flight. Patterns of urinary excretion of noradrenaline and adrenaline for a particular subject were similar for flights to different destinations, and the two tended to rise and fall together in consecutive samples of urine. Sodium, potassium, inorganic phosphate, and nitrogen were all excreted within the normal range. Parahydroxyphenyllactic acid (PHPL) was also excreted in a degree consistent with an unexceptional work load. Analysis of the respiratory end-tidal samples provided no evidence that the captains had been hyperventilating.

The findings seem to reflect the unexceptional nature of the cockpit environment and the overall demands upon the pilots in these flights. The observers all recommended that objective post-flight tests of the pilot's state of arousal and his ability to make precise judgements and accurate decisions were needed. Also needed is adequate statistical treatment of the results. The data are presented in histograms and graphs for each subject, but the levels of significance for variations in the measurements are not presented.

65

Frederick, W. S., Physiological aspects of human fatigue, AMA Archieves of Industrial Health **20**, 297–302 (Oct. 1959).

Abstract:

Reports testing of pilot fatigue for long-distance flights shortly after World War II. Subjects were "a group of persons" kept awake with no rest for 72 hours, and tested for visual acuity, dark adaptation, color perception, minimum hearing threshold, sense of equilibrium, functions of cerebrum and central nervous system (Kraepelin test, Bourden-Wiersma test, and Grunbaum test), pulse rate, respiration rate, blood pressure, urinary waste products of the adrenal cortex (17-ketosteroids). The majority of the tests never differeed from normal during the 3 days. Those that varied were those in which the cerebrum was important. Subjects showed fatigue at a particular moment only for a particular test. Defines "Functional Fatigue"—decreased capability of performing a particular test.

Also studies of world running records for 1958 by calculating the average speed (meters/sec) for the various distances run.

$$V = \frac{D}{T\text{-}C}$$

V is average speed in m/sec.
D is total distance in meters
T is time of the record in seconds
C is the start acceleration correction factor in seconds (1.0 sec for men; 1.2 for women)

Plotted logarithmically, results show 1 straight line for distances up to 1,500 m, a second straight line for events from 1,500 m to 26 miles. Indicates 2 types of runners: short-distance and long-distance. For "high" performances (8 or 9 m/sec.) objective fatigue occurs earlier than subjective fatigue, and for "lower" performances (slower speeds, but longer distances) the subjective feeling of fatigue always precedes the actual (objective) deterioration in performance.

Later pilot fatigue tests showed that simultaneous performance of 2 tasks produces in time a deterioration in performance of each of the 2 parts. Therefore measured functional pilot fatigue by giving a pilot another task to do — choice reaction time. Author developed for this an instrument called the "performance indicator," which he doesn't describe.

This is a transcription of a lecture, with one graph, but no references cited.

66

Frick, M. H., and Konttinen, A., Changes in Cardiac Output and Related Circulatory Parameters Evoked by Basic Military Training, International Review of Army, Navy, and Air Force Medical Services #11 (1961).

Abstract:

Cardiodynamic changes were observed in ten military men (ages 19–26) at the beginning of and after two months of military training. Subjects were studied in the afternoon after at least a six hour fast, under conditions of one hour's rest in a supine position and while performing a leg exercise in a supine position on a bicycle ergometer at a load of 400 kgm/min. The following measures were taken: (1) blood pressure from the brachial artery by means of a Statham manometer; (2) mean blood pressure obtained by electrical integration. Cardiac output using a dye dilation technique employing an Evans blue (T–1824) indicator; (3) a Cambridge ear oximeter; (4) calibration samples were taken three minutes after dye photo-injection; analysis being performed in a Beckman B Spectrophotometer. Cardiac output determination was repeated for the leg exercise with the dye being injected after a six minute exercise period. All subjects breathed oxygen for five minutes prior to and during the entire procedure. After determination of the exercise cardiac output, the subject was allowed to rest for a half hour, after which the physical working capacity was determined. Heart vloume (Jonsell method), body surface area (DuBois formula), cardiac index, and stroke index were calculated.

The following results were obtained: (1) the military training resulted in an increase of heart volume and physical working capacity with a slight increase of the cardiac index at rest; (2) a decrease in the pulse rate at rest and an appreciable increase of the resting stroke value; (3) left ventricular pressure work remained the same; (4) left ventricular stroke work greatly increased at rest; (5) an equal increment of the cardiac index both before and after the training period was achieved with longer stroke volume and lower pulse rate. The results for one of the subjects were disregarded for the exercise phase due to the collapsing of the subject.

The one serious deficiency in this study is inadequate statistical treatment; only means, change and percent change are indicated for the two test sessions. However, the report is fairly good in using what evidence it has to support the conclusion that the more physical training an individual has, the less strain there is on the cardiac system.

67

Geldreich, Edward W., Some physiological concomitants of mental work, Psychological Monographs: General and Applied **67** (8), Whole No. 358, (1953).

Abstract:

The relationship between physiological variables and light homogeneous mental work was explored. Records were made of the heart rate, respiration rate, relative blood pressure change and level, volumetric change of the index finger, palmar skin conductance level, and incidence of magnitude of galvanic skin responses of 10 male college students. The mental work task was color naming. Five colors were presented serially in random order by a psychergometer. The subjects discriminated each color by responding manually to a set of correspondingly colored keys. Pressing a key automatically presented the next color. The task was to learn to respond to the perceived color as fast as skill and motivation permitted. Each subject initially practiced the task (in four to seven practice sessions of a half-hour or more) until his performance stabilized. For each subject were designed four days of the color-naming task (the "mental work" [MW] condition)—days 1, 3, 6, and 10; two days of randomly tapping the five color-naming keys while blindfolded, at a rate judged by each subject to be his usual color-naming speed (the "motor component" [MC] condition) days 2 and 4; and two days of passively looking at the five random and serially presented colors at the rate of 90 per minute (the "sensory component" [SC] condition)—days 5 and 7. Each work period for all experimental conditions was 55 minutes long, preceded and followed by 10-minute rest periods (the "prerest" and "postrest" conditions). Each subject also had two days of 55 minutes each of control rest in a state of mental repose and relaxation. All the mental work days and most of the experimental sessions were at least two days apart. All 10 subjects completed, and were included in, the MW determinations. Nine subjects made up the MC determinations (one subject habitually tapped out melodic time patterns and was excluded), and only six subjects made up the SC determinations (one subject regularly fell asleep, and three could not fulfill the control condition requirements, so that their SC records were used as control records). All 10 subjects were included in the control determinations (including the SC substitutions).

Results and conclusion: (1) The trends of changes in the rate of color naming and blocking (a decrement in color naming and an increase in blocking) were not due to chance, but were due to factors present in the mental work operation and the organization of the mental worker. (2) MW respiration and heart rates were significantly greater than MC, SC, control, pre- and postrest rates. (3) A significant residue of half a respiration and about four heart beats per minute remained after subtracting MC and SC effects from the MW results. (4) Relative blood pressure significantly increased in the MW condition, but significantly decreased in the MC and SC conditions. (5) The MW level of palmar skin conductance was significantly greater than the MC, SC, control, pre- and postrest levels. (6) The level of palmar skin conductance maintained during the different forms of work was related to the task difficulty, the degree of alertness, the amount of bodily tension, and the amount of energy mobilized to respond to the task situation. (7) A true control base line for physiological activities of minimal mental alertness was difficult to maintain for a period longer than 10 minutes without the intrusion of sleep. All records of physiological responses of an hour of mental repose showed a continuous slight decline for the first half-hour, before the true base line of physiological activity appeared. (8) The changing respiration and heart rates, and the changing level of palmar skin conductance in the MW condition were positively correlated with the changing rate of color naming and negatively correlated with the changing frequency of blocking. (9) In terms of work decrement, blocking increment, personal reports of the subjects, and behavior after the experiment, fatigue was generated during the mental work.

This was an extensive experiment, precisely reported, and copiously analyzed and interpreted, with statistical techniques superior to the ordinary study. Doubt may be expressed, however, with the author's substitution of SC results for control results for those subjects who could not meet control requirements, since there was not a consistent similarity between SC and control scores in all the physiological measures. Several of the author's interpretive conclusions seemed to generalize too widely from the particular data and to introduce variables without sufficient criteria, e.g., "alertness" or "awareness." A criterion for "blocking" and the statistical level of significance were also not clearly specified. The best criticism of the "centralist" assumptions of the experimental design was given by the author himself: The MC and SC conditions were not "pure" conditions. Both sensory and motor activity were present in both; they were artificial conditions and cannot validly be "subtracted out" from the MW physiological effects. The best interpretation of the changes that occurred during the MC and SC conditions would regard the changes as being associated with different degrees of mental activity, different in degree of difficulty from that involved in the MW condition.

68

Glassner, Harvey F., and Peters, G. A., Effects of Mental Task

Difficulty on Physiological Response, El Segundo, Calif., Douglas Aircraft Co., Inc., AD #231,463 (1959).

Abstract:

This study examined the relationship of physiologic responses when the level of intellectual difficulty of a mental task was systematically varied. Bioelectronic instrumentation measured the following physiological responses: respiratory rate, respiration amplitude, respiratory index, pulse rate, pulse skin deviation, basal skin resistance level, basal skin resistance deviation, and basal skin resistance change. Mental tasks were selected from the Army General Classification Test, First Civilian Edition, Form AM, on three levels of difficulty—low, moderate, and high—for verbal, arithmetic reasoning, and pattern analysis items. Subjects (number not given) ranged in age from 26 to 36 years, and had from 2 to 5 years of college. A practice period preceeded testing, which was arranged in a Latin square design for level of difficulty.

It was found that the level of physiologic response was inversely related to the task difficulty level. An explanation of this was offered which stated that the higher the intellectual task difficulty, the more suppressed physiological responses became, as it has been shown that increased physiological responses do occur with complexity of task and tend to lower efficiency. The idea of a suppression factor would then operate to safeguard the organism from disruptive effects during a highly complex task.

The authors suggested that the problem of the differences in sensitivity between the physiological measures could be alleviated by using a combination of measures, resulting in greater reliability. Such a combination of measures could be selected on the basis of the greatest number of significant high-low task differences, an equitable representation for each of the major physiological functions involved, and appropriate consideration of the bioelectronic instrumentation requirements. As an example, the authors proposed a combination including respiration rate variability, mean respiration amplitude, mean pulse rate, pulse rate deviation variability, mean basal skin conduction, and basal skin resistance deviation variability.

This study utilized good methodology and statistical treatment of results (Chi-square, *t*-tests, etc.). It contains good development and discussion of the problem and of future research areas. It was noted in the text that there were large individual differences in the results. Indications were that there was not a sufficient number of subjects to mask the hyper- and hypo-responsive individuals, which fact probably influenced results a great deal. This study should be repeated using a larger sample.

69

Goldman, R. F., Energy expenditure of soldiers performing combat type activities, Ergonomics **8** (3), 321–327 (1965).

Abstract:

The report deals with the measurement of energy expenditure of troops in a simulated combat activity, tactically controlled, under conditions of various marching speeds, activities, and with and without loads. Twenty-four infantrymen were measured in various combat activities to obtain 38 measurements, with the average ambient wet bulb globe temperature (WBGT) index being 83 during these measuring periods. A Müller-Franz respiratory air meter was used to take a timed respiratory volume measurement and the oxygen content of the expired air was measured using a Beckman Model E paramagnetic oxygen analyzer. Caloric expenditure was calculated using the method suggested by Weir (1949).

Limitations in the study included the following: (a) Fear and fatigue that is present in true combat was lacking. (b) the gas mask and the expiratory gasometer hose probably contributed some impedance to respiration and may represent a significant portion of the energy cost of breathing even though it was a modest percent of the total. (c) Clothing resulted in elevation of body core temperature and thereby may have produced a temperature-induced increase in metabolic rate. (d) The subjects may have been somewhat dehydrated. The resultant load on the cardiovascular system of combined effects of the dehydration and clothing may have increased the energy cost but only to a small percent of the total.

The findings were: (1) The upper range of the rate of energy expenditure was about 6.7 to 7.5 kcal/min. (2) The energy cost values were independent of the terrain, as the soldier was allowed to work at his own pace. (3) The relationship between ventilation volume and energy expenditure was found to be linear. This indicates that a calculation of energy expenditure might be made using a formula to convert ventilation volume.

This report adequately covers its objectives, but is lacking in statistical analysis and detailed explanations and conclusions. Reference should be made to the Winsmann and Daniels report (1956) dealing with a similar problem.

70

Grandjean, Etienne. Nervous fatigue in telephone operators and office employees. Internationale Zeitschrift fur Angewandte Physiologie, **5**. pp. 400–418 (1959).

Abstract:

In order to study the effects of fatigue due to the strenuous occupation of long distance telephone operators, we determined before and after a work shift the performance of some psychophysiological functions. Each of the used psychophysiological tests was investigated for a period of 4 weeks on 13 —15 female telephone operators.

The flicker fusion frequency was decreased after the work shift in all telephone operators. Since the illuminating conditions could have been partly the reason of that decrease, we repeated the same measurements in summer under daylight conditions and found in the second series in 12 of 13 subjects also a decrease which was certainly less important than in the first series but in the mean still highly significant.

The equilibry movements were increased after the work shift in 6 of 15 telephone operators. The increase of the mean value of all subjects of about 10% is not highly significant ($0,05 > p > 0,01$).

The optical reaction time was increased in each of the 14 telephone operators; the increase was statistically significant in all but one. The mean increase came to 2/100 seconds.

The calculating performance showed in the mean no significant change after the work shift. The time used for 30 additions as well as the number of mistakes were not characteristically modified.

The vigilance test (BOURDON) showed that, in the mean, 9 of 13 telephone operators had, after the work shift, a shorter time value for the cancelling of letters. The mean decrease of the whole group is statistically highly significant. The number of mistakes was, in the mean, not significantly higher after the work shift.

The manual skill test showed in 12 of 14 telephone operators a lower performance after the work shift. The difference is in the mean highly significant.

The registration of the tremor revealed in 11 of 15 telephone operators a small and mostly not significant decrease after the work shift. The mean difference is secured by $p = 0.02$.

In all but one of the measured psychophysiological functions we note a decrease of the performance after the work shift. The only exception are the results of the vigilance test (BOURDON). We interpretate these phenomena as a consequence of a decrease of cortical inhibitions in a state of fatigue.

We repeated the measurements of all these psychophysiological functions, excepted the vigilance test, in a group of 14 female bureau employees.

This group showed also in the mean a tendency for a decrease of the performances after the work shift. The comparison of both professional groups shows clearly that the decrease of the psychophysiological performances is less important in the bureau employees than in the telephone operators. The difference between both groups is especially marked in the optical reaction time and the flicker fusion frequency, where it is highly significant. These two tests seem to be a good method for the physiological evaluation of fatigue of this professional work load. (Author's Summary)

A very good report with charts, figures and tabulated results.

71

Grandjean, E., and Jaun, H. W., Fatigue Phenomena in Telephone Switchboard Operators During Night Work. Zeitschrift fur Praventivemedizin, Zurich 5, No. 5–6, 143–152, (1960).

Abstract:

Three psychomotor functions of long distance telephone operators were measured during their night-shift, in order to study the physiological symptoms of fatigue during night-work. The tests were carried out on 25 subjects before, during and after a half night-shift ending at midnight, and on 14 subjects before and after a complete night-shift ending early in the morning. The investigations gave the following results:

1. A manual skill test showed in the mean a significant decrease during the half night-shift; the decrease during the whole night-shift was not significant.
2. The flicker fusion frequency decreased in the mean by 2,1 Hz for the half night-shift and by 1,3 Hz for the whole night-shift. Both changes were significant.
3. The optical reaction time increased in the mean by 1,2 1/100 s for the half night-shift, and by 1,3 1/100 s for the whole night-shift. Both changes were significant.

The comparison of these results with previous analogous investigations on telephone operators during the day-shift showed that the modifications are in both cases of the same quantitative order.

These results are discussed on the base of present knowledge of neurophysiology. (Authors' Summary)

A good report with many tables and figures.

72

Green, Norman E., Fatigue and Tension in SAGE Operator-Team Performance: A Sociological Analysis, Bedford, Mass., USAF Operational Applications Office, AFCCDD TN 60–15, DDC AD #239,461 (1960).

Abstract:

A sociological approach to fatigue and tension was used in this study of operator-teams in the SAGE (Semi-Automatic Ground Environment) Direction Center. There are eight different functional activities or operator-teams making up each operating crew at the Direction Center. Four crews, involving 194 individuals, were given a questionnaire about various human factors aspects of their work.

Results: (1) Forty-four percent of the total group agreed that more chances for periodic relaxation would increase work effectiveness, and 85 percent agreed that certain job requirements and conditions made the duty shifts quite tiring. Sixty-five percent of the group reported little or no tension or conflict among those with whom they work regularly. The author concludes from these results that fatigue and tension were clearly present.

(2) There were also real differences between work groups (functional activities) in the extent of the fatigue and tension reactions expressed.

(3) Spearman Rank Correlations and analysis in terms of percentage figures indicated ($p \leq 0.05$) that the functional activities expressing more fatigue and tension also expressed: (a) less successful adjustment to operational pressure, (b) less cohesiveness, (c) less satisfaction with information channels, and (d) less favorable reaction to the supervisory structure.

(4) While all six variables were significantly interrelated ($p \leq 0.05$), the group cohesiveness factor was believed to be the most efficient single "predictor" of all the others.

(5) Analysis of variance by ranks indicated that each of the eight work groups tended to maintain a stable rank order position with respect to the other work groups on each of the six variables tested ($p < 0.001$). The author concluded that a major portion of this variation in work group behavioral patterns was explained by differences between the eight functional activities in work processes, job requirements, and work conditions. These possible differences were not, however, discussed by the author.

This study is very good, although a more complete description of the procedures used for selecting the sample and administering the questionnaire would have been welcomed. As only seven items out of a much longer questionnaire are discussed in this report, it might have been helpful to present the entire questionnaire in an appendix.

73

Greene, James H., and Morris, W. H. M., The design of a force platform for work measurement, The Journal of Industrial Engineering 10 (4), 312–317 (1959).

Abstract:

The general design and some construction details of a force platform are presented. Its operation is stated to be "very reliable," but no operational data or sensitivity limits are given in this report. The worker is supported on a sheet of ½" plywood in the shape of an equilateral triangle approximately 32" to a side, and covered with a corrugated rubber mat. The plywood is supported by a platform frame made of 2" tubular steel, in turn supported at the three corners by steel ball bearings resting on adjustable high-strength aluminum deflection cantilever beams. Horizontal movement is restricted by two sets of beams, also acting through ball bearings. Linear-variable differential transformers are used as the three sensing elements on the platform, and the outputs are recorded by a Brush Universal Analyzer.

74

Griffith, J. W., Kerr, Willard A., Mayo, Thomas B., Jr., and Topal, John R., Changes in subjective fatigue and readiness for work during the eight-hour shift, J. Applied Psych. 34, 163–166 (1950).

Abstract:

A total of 379 subjects (232 male manual workers. 75 foremen, and 48 male and 24 female office workers) were given a subjective list (a Kerr "tear ballot") each half hour of an eight hour work day to determine whether employees in various types of work possess definite attitudes as to what time during the work shift they were most tired and when they felt rested. It was found that: (1) older workers were more aware of being tired than younger workers. (2) Females tended to report greater extremes of tiredness than did males. (3) Curves of work feeling during the day for all three groups were highly similar; and it appeared that the extent of subjective tiredness was in part a function of the degree of manual effort involved in the jobs performed. (4) Maximum subjective fatigue was evident in the fourth and eight hours. (5) Maximum restfulness was reported in the second and sixth hours.

A fairly good idea, but the study is lacking in adequate explanation, development and statistics. There was not controlled sampling of subjects, for e.g., some of the manual workers were on night shift, others on day shift; the foremen were sampled at a club rather than on the job. These were some factors which need to be controlled for in future studies.

75

Hanes, Bernard, and Flippo, Edwin B., Anxiety and work output, The Journal of Industrial Engineering 14 (5), 244–248 (1963).

Abstract:

The relationship between one aspect of fatigue, the decline in output measured in both unit of work and in time units, and test anxiety in the workers was examined in a laboratory situation. The IPAT Self Analysis Form was administered to over 200 older college students (average age was 26 years). The 20 students scoring in the lower three deciles of the test were selected for the low anxiety group. and the 17 students in the upper three deciles were called the high anxiety group. The subjects performed one at a time in relative isolation on a modified Barnes pegboard set with five columns of six holes each. A work unit consisted of filling one column,

and, as the board was continuously cleared by the pegs falling through the holes, the subject was able to do as many units of work as he was capable of without having to stop to remove pegs. The subject was seated at a table, and strain was introduced by mounting the board 12" above the table and requiring the subject to keep his elbow high. After a few practice trials, the subject was asked to work as rapidly as possible for as long as possible.

The average number of work units completed by the low anxiety group was 35.80, and by the high anxiety group, 24.65. Standard deviations were 6.4 and 9.6 respectively, and a t-test indicated that the difference between the means was significant at the 0.01 level. It was felt that this difference in output was unaffected by differences in height or weight between the two groups—which the authors considered to be insignificant. There did not appear to be a significant difference between the two groups in the amount of time taken to complete a work unit. The mean time per work unit for the low anxiety group was 0.152 minute (SD = 0.0331), and for the high anxiety group, 0.149 minute (SD = 0.0317). No gradual decline in output (time per work unit) was found. The variability among the subjects appeared to be significant. Seventy percent of the highly anxious subjects reported feelings of fatigue on or before the tenth work unit, while only 17 percent of the low anxiety group felt tired by that time.

Two major factors adversely affect the value of this study: (1) Differences between or among groups in terms of height and weight, time per work unit, and point of onset of subjective fatigue, and between trials in time per work unit were not reported to have been analyzed statistically. (2) The mean number of work units performed was artificially lowered for each group by the experimenters' stopping work at the completion of 40 units. While only three members of the high anxiety group were able to complete 40 units, 11 of the low anxiety group did. Had every subject been permitted to work to exhaustion, both group means would have been higher, and the difference between them probably greater than that obtained.

76

Hansen, James E., Harris, Charles W., and Evans, Wayne O., Influence of elevation of origin, rate of ascent and a physical conditioning program on symptoms of accute mountain sickness, Military Medicine **132** (8), 585–592, DDC AD# 659,696 (1967).

Abstract:

Two studies of mountain sickness were performed with Caucasian volunteer soldiers, ages 17 to 24, and free of recognizable cardiovascular, pulmonary, gastrointestinal, muscular, skeletal, and central nervous system disease. In study I, 6 subjects from sea level and 7 subjects who had been stationed for 2 to 18 months at an altitude of 5,000 to 6,000 feet were transported within several hours to 11,400 feet, where they remained for 3 weeks. In study II (also discussed by Vogel, et al. 1967), 24 subjects were divided into 3 groups of 8: the first remained at sea level; the second was transported rapidly to 14,100 feet; and the third was transported slowly to 14,100 feet with 1-week stops at the intermediate altitudes of 5,200 and 11,400 feet. In both studies, each subject filled out a 39-item symptom check-list daily between 6 and 7 PM, reporting on his feelings during the previous 24 hours. Symptom words and phrases were tabulated under 4 categories: neuromuscular, cardiopulmonary, gastrointestinal, and other. Each subject was interviewed at the end of the study by a single physician who inquired about illness and fitness for duty during the study, and conducted a detailed system review.

Results: (A) Study I. The group starting from 5,200 feet showed no significant change in rating of symptoms with movement to 11,400 feet. In those subjects coming from sea level, neuromuscular and cardiopulmonary category scores differed significantly from sea level values for the first 3 days at 11,400 feet ($p < 0.001$ and $p < 0.025$, respectively), while the gastrointestinal category score change was insignificant ($p \sim 0.08$). All scores returned to baseline values within 1 week at 11,400 feet. During the first day that the subjects coming from sea level spent at altitude, headache and insomnia were found in all 6 subjects, dyspnea and light-headedness in 3, and poor concentration and fatigue in 2. A lessened desire to work was equivocally seen in both groups at altitude.

(B) Study II. In the rapid ascent group, neuromuscular, cardiopulmonary, and gastrointestinal scores increased significantly in the first 3 days at 14,100 feet ($p < 0.02$, < 0.02, and < 0.01, respectively), while in the slow ascent group the changes from sea level were less significant ($p < 0.10$, $p < 0.05$, and no change). By the second week at 14,100 feet, only the cardiopulmonary scores were still changed from sea level values ($p < 0.05$ level in both groups). Headache, insomnia, fatigue, nausea, and anorexia were experienced more frequently in the rapid ascent group than the slow ascent group; dyspnea was reported equally in both groups.

This report, the one by Vogel et al. (1967), and others about the same experiments, form an excellent, well detailed series.

77

Hanson, Harold E., Physiological Response Changes of Men Attributable to Body Armor, Sun, and Work in a Natural Desert Environment (Including Negro-White Differences), Natick, Mass.. U.S. Army QM Research and Engineering Center, TR–EP–148, DDC AD #262076 (1961).

Abstract:

Sweat production, rectal temperature, and pulse rate were measured over a period of 24 consecutive days on 8 matched Negro-White pairs of soldiers in a hot desert environment. These indices were used to determine the effects of exposure to sun, exercise, and wearing an eight-pound armored vest. The study encompassed eight combinations of environment (shade and sun), attire (clothed and clothed plus armor), and activity (resting and walking). Each pair of subjects encountered each condition three times, and had one two-hour test session daily. Nude and clothed weights were taken at the start and finish of each test session, as well as rectal temperature by a clinical thermometer, and pulse rate. Resting subjects remained relatively inactive, reading or conversing with a companion; exercising subjects walked at a rate of three miles an hour. Water in canteens which were weighed before and after each test was provided ad libitum. Mean meterological data were: dry bulb 101.7° F, relative humidity 10.8%, windspeed 9.8 mph, and solar radiation 917 kg cal/m².

Results: (1) When subjects wore the armored vest, progressive increases occurred in sweat production with exposure "shade to sun" or "rest to exercise," while sweat evaporation essentially decreased. Rectal temperature and pulse rate also increased significantly. The author concluded that the armor interferred with sweat evaporation, thus creating a heat load. (2) When an individual was exposed to the sun, significant increases occurred in sweat production and evaporation. Rectal temperature increased in the sun only when armor was worn, and pulse rate increased significantly only during exercise. (3) The effects of exercise, under any of the environmental and clothing conditions, were to significantly increase sweat production, evaporation, rectal temperature, and pulse rate. Sweat production and rectal temperature increases were inversely related to environmental intensity, while pulse rate increases were directly related. (4) Variance analysis of sweat production, evaporation, and rectal temperature revealed no significant differences between the Negro and White subjects. There were no significant differences between Negros and Whites for mean stature, fat-free weight, or percentage of body fat. The author concluded that the heat tolerance of fully clothed Negro and White subjects, when exposed to a natural hot-dry desert environment is about equal.

The very small sample size decreases somewhat the excellence of this study.

78

Hauty, George T., and Adams, Thomas. Pilot Fatigue: Intercontinental Jet Flight, 1. Oklahoma City to Tokyo and Back, Federal Aviation Agency. Office of Aviation Medicine, Report AM 65–16, DDC AD #621,433 (1965a).

Abstract:

Research was conducted on the disruption of physiological day-night cycling that occurs when pilots are rapidly translocated through many time zones on intercontinental flights. The time lag for biological phase shifts and the effects on performance proficiency were studied on both an East-West and a West-East flight. Subjects whose daily habits of work and sleep were fairly representative of the general male population were selected, to provide a reference standard for later research on intercontinental-air-carrier crews. The subjects were six male volunteers, drawn from a medical-school population, three of whose ages ranged from 19 to 23 years, and three from 40 to 48 years. Following three consecutive days of preflight observation in a clinical research ward at Oklahoma City, the subjects took an 18-hour jet flight to Tokyo and remained there in a military hospital for 10 days, during which studies were conducted on alternate days. On the 11th day, the subjects took a 17½-hour jet flight back to Oklahoma City, where they underwent three consecutive days of postflight testing. The measures taken were: (A) Rectal temperature—a rectal thermistor probe was worn by each subject continuously throughout the 24-hour day of assessment, and temperatures were recorded at 30-minute intervals. (B) Reaction time—the speed of the subject's manual response to (1) a single auditory stimulus, (2) a single visual stimulus, and (3) one of several possible visual stimuli ("multiple-choice") was measured at 4-hour intervals from 0700 to 2300 hours. A "decision time" measure was computed by subtracting the mean time of reacting to the single visual stimulus from the mean time of reacting correctly to one of several possible visual stimuli, taking this value to represent the average time required by the subject to "decide" which of the possible responses was correct. (C) Critical flicker-fusion—Three ascending and three alternating descending thresholds were determined at the above times. (D) Subjective fatigue—The level of fatigue perceived by the subject was measured at the above times by a scaled check list. The preflight measurements in Oklahoma were the reference standard to be compared with Tokyo values; measurements from the last day in Tokyo were the reference for postflight values following the return to Oklahoma.

The results: As indicated by mean rectal temperatures, it took the subjects three to five days to shift into phase with Tokyo time, and one day for the shift back in Oklahoma. Interindividual differences in lag time were profound in that a completed shift was shown on the first day in Tokyo by one subject, while another subject did not demonstrate a normal phase shift on any of the days in Tokyo. Behavioral integrity was degraded during the transitional period in Tokyo and to a lesser extent during the period of transition back to the environment of origin. It took three days in Tokyo for reaction time to return to preflight levels, and two days for the shift back in Oklahoma. Assessment of subjective fatigue was complicated by the factor of boredom. No significant change in the threshold value of critical flicker-fusion took place throughout the experiment. The older group of subjects generally reported higher levels of fatigue and evidenced slower reaction times than those of the younger subjects.

This was an adequately designed and reported experiment, with statistical analysis applied to the results. The report covers only the first stage of a series of experiments to be carried out on pilot fatigue on intercontinental flights; the control group (lacking in this study) will be tested in a later experiment on a North-South round-trip flight, enabling appraisal of those effects solely attributable to prolonged flights, without time-zone changes. Improvements in the experimental design might include daily measurements in Tokyo (testing on alternate days may not be adequate for significant behavioral changes that take place in one to three days); a longer reference standard for postflight values than the one last day in Tokyo (the preflight reference was three days); a larger sample of subjects (especially if differences are to be noted for the younger vs. the older group); and a more detailed reporting of methodology of the reaction-time tests. It is suggested that results should not be generalized for intercontinental flights east of Oklahoma, since the direction of the time difference (a certain number of hours earlier rather than later) might be important.

79

Hauty, George T., and Adams, Thomas. Phase Shifts of the Human Circadian System and Performance Deficit During the Periods of Transition: I. East-West Flight. Federal Aviation Agency, Office of Aviation Medicine. Report AM 65-28, DDC AD #639,637 (1965b).

Abstract:

This report is of a follow-up study to Hauty and Adams (1965a), and involves a jet flight from Oklahoma City to Manila and return. Periodic biomedical assessments were made on alternate days during the week immediately prior to flight, during an eight-day layover at Manila, and during the week following return to Oklahoma City. The assessments were repeated at 0700, 1100, 1500, 1900, and 2300 hours (local time) on each testing day. The following measurements were made: (1) Rectal temperature, noted every 30 minutes from a continuously-worn thermistor probe. (2) Evaporative water loss. For each 25-minute assessment period, a small plastic capsule, sampling from a 1 cm² skin area, was sealed to the skin at the center of the left palm. (3) Heart and respiratory rates were measured each test period with a lightweight chest strap housing three silver electrodes for heart-rate measurement and a mercury-in-rubber strain gauge to monitor respiratory rate as a function of changes in chest circumference. (4) Reaction times to a variety of stimuli and stimulus conditions were measured with a Lafayette Multi-Choice Reaction Timer modified to preclude secondary cues. (5) Decision time was taken to be the average time required to "decide" which of three possible responses was the correct one to be made at six successive and randomly determined presentations of one of three possible visual stimuli. (6) Critical flicker-fusion was determined by three ascending and three alternately descending thresholds. (7) Subjective fatigue was measured with checklists developed by the scale-discrimination method. Four healthy, adult, male volunteers from the professional and technical staffs of the Civil Aeromedical Research Institute served as subjects, and were instructed to maintain their daily living habits in accordance with the local time of the overseas destination immediately following arrival.

Rectal temperature and heart rate required approximately four days to shift to the Manila time, while palmar evaporative water loss took nearly eight days. Both reaction time and decision time were slower on the first day in Manila, but returned to near normal by the second day. Respiratory rate did not show a periodicity of well-defined and consistent nature. CFF thresholds did not change significantly. Subjective fatigue increased significantly ($p = 0.001$) on the first day in Manila, but returned to the mean preflight level by the second day and remained there.

Whereas the flight to Manila was made in a total of 23 ½ hours with no more than 2½ hours for any layover, the return flight required a total of 34 hours and an overnight layover in Los Angeles. The first day of postflight assessment for this return trip followed the day of arrival in Oklahoma City. Both rectal temperature and palmar evaporative water loss curves showed a complete shift in phase to Oklahoma City time on the first postflight measurement day. The mean levels of internal temperature and of water loss fell to the Oklahoma City preflight level on this day also. Heart rate apparently did not shift back to Oklahoma City time until the third day. Reaction time, decision time, and subjective fatigue were changed on the first postflight day, but to a much lesser extent than on the first day in Manila. Duration of behavioral impairment was much shorter than the lag time of physiological phase shifts after both flights.

80

Henschel, A., et al., Heat Tolerance of Elderly Persons Living in a Sub-Tropical Climate, Dept. of Health, Education and Welfare, Bureau of Disease Prevention and Environmental Control, TR-35, DDC AD #651 479 (1967).

Abstract:

This study measured the effects of aging and associated conditions on the physiological responses to a standardized environmental heat and work stress at different seasons of the year. The subjects consisted of 100 volunteers: 68 males, mean age 72; and 32 females, mean age 69. All were of good or very good health; blood cholesterol levels did not exceed the normal range, and electrocardiograms were within normal limits for 56% of the males and 63% of the females. This sample was considered to enjoy better health than other groups of similar age and background. The majority (over 75%) of the sample, at the time of the test, had not smoked for 10–15 years or had never smoked.

The experimental design was as follows: (1) a 70 minute exposure in a controlled environmental chamber at 92° F. dry-bulb, 82° F. wet-bulb temperature, resulting in an effective temperature of 85° F. and a Relative Strain Index of 0.5. (2) S rested for 10 minutes on a Lanooy bicycle ergometer, worked 5 minutes on the bicycle set at a resistance requiring 10 watts of external work; rested 10 minutes; worked 5 minutes at 20 watts; rested 10 minutes; worked 5 minutes at 30 watts; rested 10 minutes; worked 5 minutes at 40 watts; rested 10 minutes. (3) Pedaling speed was maintained at approximately 50 rpm. (4) During the ninth minute of the first rest period and the fifth minute of each work period, heart rate (EKG), ventilation rate and volume (Edwards mask and dry gas meter), and oxygen consumption (Bechman paramagnetic O_2 analyzer) were recorded. Body weight was recorded before and after the test. (5) The standard work-in-heat test with all measurements was completed by 100 subjects on two occasions: at the end of the summer season after several weeks or months of exposure to a natural hot-wet environment (St. Petersburg, Florida), and at the end of the winter season after the outside temperature had been mild to cool for several weeks.

Results: (1) With each increase in work level, a corresponding increase in pulse rate, ventilation, and oxygen consumption occurred. Females displayed higher pulse rates and oxygen consumption per kilogram of body weight at 30 and 40 watt work levels than did males. (2) No differences were found between rest pulse rates and oxygen consumption values for summer and winter. (3) Pulse rate, ventilation rate, total oxygen consumption and oxygen consumption per kilogram of body weight were all higher in the winter than summer. It was suggested that this was due to more out-of-doors activity in the summer, and therefore, better physical condition of the subjects. (4) It would appear that elderly persons who are free from active disease processes can tolerate a moderate heat-work load without difficulty. (5) It was concluded that the incidence of heat intolerance would be substantially higher in older people. This conclusion was based on previous studies with a younger sample in which comparison of pulse rate under conditions of heat and work at a level of work that required an O_2 consumption four times resting value pulse rate were made. It was found that the older females had pulse rates 10–15 beats per minute lower than the group of young and middle aged women and that the males had pulse rates of 2–6 beats per minute lower than the group of young and middle aged coal miners. However, it was found that with increased work and heat levels (not specified in this report), the results were reversed.

This is a well organized study. The authors are very thorough in presenting the possible variations in their sample which could have biased the results in a favorable direction, e.g., the fact that the sample used was considered to be above average in health for their age category. There is limited statistical treatment of the results—only the means and standard deviations of the variables are presented. More detailed analysis of the results is needed before the validity of this study can be determined.

81

Herbert, Marvin J., Analysis of a Complex Skill: Vehicle Driving, Ft. Knox, Ky., U.S. Army Medical Research Laboratory, Rept. #581, DDC AD #411, 205 (1963).

Abstract:

This study dealt with the construction and administration of a valid and reliable driving-skill test battery. One hundred eighty male Air Force and Army volunteers served as subjects ($\bar{X}$ age = 22 years; $\bar{X}$ driving experience = 5.5 years). The test course was a hard-pan surface in the Yuma Desert. All subjects drove a M37, 3/4 ton, 4-wheel drive Dodge truck over the test site. Scores were obtained on each test, where appropriate, for: (a) total time; (b) number of errors; (c) number of direction changes (shifts); (d) time-in-error; (e) distance-in-error; (f) tracking error for front wheels only. Subjects were assigned to one of the experimental conditions based on his driving experience. The following tests were used:

(1) *Precision steering:* driving first in forward and then in reverse down a straight path 6.5′ × 200′.
(2) *Figure "8":* driving around an "8"-shaped path 7′ in width, with one circle 30′ in diameter and the other 50′.
(3) *Flag:* driving forward and passing alternately to the right and left of each of ten successive flags 30′ apart. The same procedure was repeated in reverse.
(4) *No-slip back:* driving up a steep incline, stopping, and then resuming travel to the top with no backward slipping.
(5) *No-slip forward:* driving down a steep incline, stopping, and then backing up to the top with no slipping.
(6) *Mirror reverse:* backing the truck down a straight path 6.5′ × 167′ using the side-mirror only.
(7) *Non-visual:* a straight, crushed-rock path 12″ × 167′ set flush into the desert hard-pan. The two left wheels of the truck were positioned on the rock path at one end; the driver wore black-out goggles and was instructed to drive forward to the far end without leaving the rock path.
(8) *Parallel-park left and right:* parking the truck in a stall located on the left or right side of the driver.
(9) *Trailer-back:* required the driver to back a trailer into a narrow stall under conditions of limited turning space.
(10) *Maze:* required the subject to back his truck through a maze with 8′ wide by 20′ long alleys.
(11) *Contour:* a trough 180′ and 32′ wide which wound around high and low terrain. The subject's door window was blacked out, and he had to drive through the interlocking circles in a clockwise direction and stop at his starting point.

The study was run for two months, five subjects a day. The experimental groups were differentiated on the basis of the number of hours of desert driving (0, 1, 3, 7, or 9) that they were required to drive in order to induce fatigue. These driving hours were required after an initial test on the above items and prior to retest on the battery. The 36 subjects who had no fatigue driving (0 hours desert driving) were retested one hour after their first test. All other subjects were retested immediately after completing the fatigue course.

All data were subjected to product-moment coefficients of correlation with these results: (1) initial scores and hours of driving—no significant correlation; (2) post-fatigue scores and hours of driving—significant at the 0.05 level of confidence; (3) initial test and retest scores of the 36 subjects in the no-fatigue group gave test-retest reliability estimates for each measure. Thurstone's Centroid method of factor analysis was applied in order to load each factor in the tests.

It was concluded that: (a) This test battery was shown to exhibit reliability and validity of the measures given, and might be considered as a practical device to be used in the licensing and skill-evaluation of vehicle drivers. (b) Hours-of-driving was proven to be a valid criterion for assessing the adequacy of the test of the skill. This criterion induced levels of stress which inversely affected the level of skill being shown by the battery. (c) Five basic skill factors were identified: Multilimb Coordination, Spatial Orientation, Proprioception, Response Orientation, and Reaction Time.

This was a well-executed and thorough study. It isolated five skill factors associated with vehicle driving with reliabilities of 0.35 to 0.88. It now remains for the test battery to be used in order to assess the effects of driving conditions and time on the above identified skills.

82

Herbert, Marvin J., and Jaynes, William E., Performance Decrement in Vehicle Driving, Ft. Knox, Ky., U.S. Army Medical Research Lab. Report No. 597, DDC AD #430,226 (1963).

Abstract:

The purpose of this paper was to investigate the effects of driving fatigue on task performance. The test battery consisted of nine tests: four "jockeying" tests to emphasize spatial perception, response orientation, and multilimb coordination; three "tracking" or precision steering tests emphasizing response orientation, proprioceptive feedback, spatial orientation and multilimb coordination; and two tests to measure gross reaction times and multilimb coordination. Tests were scored for total time, number of errors, number of direction changes, time-in-error, and distance-in-error. One hundred eighty-five males were divided into groups of five, given limited directions and told to proceed. Only five Ss a day were tested in one of five conditions, i.e., testing before and after 0, 1, 3, 7 or 9 hours of truck driving. S was given a five minute break in each hour and a ten minute break for lunch. Subjects showed progressive deterioration in test performance up to seven hours, but no decrement was observed after that period. All 15 test scores yielded part correlations significant at the 95% level of confidence or better. Correlations reached a maximum of $R = 0.50$.

This is a good study, containing adequate development and statistical treatment of the problem.

83

Hess, E. H., and Polt, J. M., Pupil size as related to interest value of visual stimuli, Science **132**, 349–350 (1960).

Abstract:

This study dealt with two areas: (1) devising the best method to record pupil dilation; and (2) determining the effect that emotionally toned or interesting visual stimuli have on pupil size. Through trial and error, the best method of analyzing pupil size changes was determined to be by photographing the eye with a 16mm movie camera, projecting the film with a Percepto-Scope, and measuring the pupil diameter on the projected image. Six subjects (4 male, 2 female) viewed five pictures of varying interest and emotional content while the eye was photographed under constant illumination. The results and test-retest results indicated that change in pupil size was positively associated with degree of interest or emotion in what was viewed ($p < 0.01$). Further experimentation was proposed, including the study of auditory effects on pupil dilation.

This would have been a much better study if controls and more subjects had been used. It is also lacking in statistics.

84

Hess, Eckhard H., and Polt, James M., Pupil size in relation to mental activity during simple problem-solving, Science **143**, 1190–1192 (1964).

Abstract:

Four men and one woman, judged (by level of education achieved) to be above average in intelligence, served as subjects in a study to determine the relationship between pupil size and mental activity during simple problem-solving. The subject was placed in a stationary position and, by means of a mirror, pictures of his eye were taken at two frames per second. S was instructed to fixate on a number "5" on a screen 1.45 m from him and solve orally simple multiplication problems which the experimenter read to him. After the camera had run for 30 seconds, the first problem was given; 5 to 10 seconds elapsed between problem solution and presentation of the next problem. Measurements of pupil size were calculated from the film as viewed with a Percepto-scope. It was determined that pupil size increased up to the point of problem solution and then decreased to its normal size. From this the authors deduced that a correlation between pupil dilation and problem difficulty exists. The suggestion was made that the pupil response would prove to be a valuable tool in the study of problem-solving and other mental processes, which have to date been largely a matter of subjective responses on the part of the subject.

This study contains thorough explanation and development of the problem and procedures. It is lacking in statistical treatment and in an adequate sample.

85

Holmgren, Gary L. and George S. Harker, Characteristic Pace as Determined by the Use of a Tracking Treadmill, Fort Knox, Ky., U.S. Army Medical Research Laboratory, Report No. 685, DDC AD 645454 (1966).

Abstract:

Nineteen male subjects who had just completed six months basic training walked on a treadmill to determine their "comfortable-but-determined" (C–D) pace. The treadmill was modified so as to adjust its speed automatically to the subject's speed of walking at any given moment. The task for each subject on each of 3 days of testing was (1) 2 short walks of 4 or 8 minutes each, starting from either a fast walk (5 mph) or a slow walk (2 mph) during which they either decelerated or accelerated their pace to reach their C–D walking pace; (2) a 30-minute walk at their C–D pace; and (3) 2 short walks again starting from either a fast or a slow walk to adjust their pace to reach their C–D pace. There was a 5-minute rest period between each condition.

Results of analysis of variance and product moment correlations of the 30-minute C–D pace indicated that: (1) subjects exhibit a characteristic C–D pace that is fairly stable on any one testing day; (2) subjects' characteristic C–D paces differed from each other ($p < 0.001$); (3) the subject's C–D pace may vary at a statistically significant level from day to day; (4) subjects' C–D pace was most reliable between the second and third test day ($p < 0.01$). It was not indicated whether or not the 3 days on which a subject was tested were consecutive. The effect of initiating a walk with a fast pace versus a slow starting pace in terms of the C–D pace the subjects attain has not yet been analyzed.

Further research, using more subjects and controlling for various psychological and physiological variables, is contemplated. The authors hypothesize that the measures likely to be the most meaningful in further research will be (1) the subjects' variance (instability) of the C–D pace on any given day; and (2) the variance of the subjects' C–D pace from day to day. These measures could be a valuable indicator of a subject's fatigue state on any given day.

This is an excellent project, and the data are thoroughly analyzed. The amount of variation of a subject's C–D pace both within and between test sessions could possibly be used as a measure of his fatigue state when measurements are made over a long enough time to establish a base line.

86

Hueting, J. E., and Sarphati, H. R., Measuring fatigue, Journal of Applied Psychology **50** (6) (1966).

Abstract:

Fatigue was induced in eight subjects by having them perform an exercise on a bicycle ergometer during 11 minutes on each of 13 days. The starting work load of 3 watts was increased every minute by 10% of the final minute's load which was varied day to day between 70–130 watts. The subjects were not aware of the increase in the slope of the work. At the end of the exercise period and during the recovery period, S filled out a number of subjective reports to indicate how fatigued he felt.

It was found that S could best estimate his fatigue by direct rating methods rather than compare it with such measures as white noise intensity. All Ss showed significant correlations ($p < 0.01$) between subjective feelings of general physical fatigue—as expressed on different kinds of rating scales—and the slope of work load. A factor analysis was performed which suggested two factors: increasing fatigue and decreasing fitness as related to measurements of fatigue, i.e., during exercise, there was an increase of tiredness with a decrease in fitness; and during recovery there was a decrease in tiredness with an increase in fitness. There was adequate statistical treatment, but the entire study exhibited little more than average investigation.

87

Hunsicker, P. A., A Study of Muscle Forces and Fatigue, Aero Med. Lab., Wright-Patterson A.F. Base, Ohio, WADC Technical Rep't. 57–586, DDC AD #131 087 (1957).

Abstract:

Three research studies were conducted to test the strength an individual could exert while seated in a simulated pilot-seat. Three samples of subjects were employed, all university students, with the physical characteristics and age span of an average pilot trainee group. The following studies were made: (1) 30 subjects used the Kinematic Muscle Study machine to determine the strength they could exert while seated in a simulated pilot-seat, grasping dynamometers with arms and hands in selected positions. One-hundred-twenty strength tests were required of each subject, testing the various combinations of 6 movements, 2 hands, 2 positions of the wrists (supinated and pronated), and 5 different angles of flexion of the elbows. Each test lasted 5 seconds, and a one minute rest was allowed between tests. Sixty tests each were given on separate days and within a week of each other, testing pronated and supinated hands separately. Since the dynamometers gave readings in 3 axes for each test, resultant forces were calculated, and the higest of the 3 resultants for any given test was selected for describing the data. The results were presented in percentile tables and in graphic form. (2) 25 subjects were tested to determine the amount of strength possible in wrist supination. The 4 tests (2 hands in the 2 positions) were carried out on a Kellogg Universal Dynamometer. (3) 6 subjects were tested for strength decrement over a 42-hour period in which the subjects were tested hourly. Their sleep was restricted to a total of 4 hours in a 48-hour period, and they were tested from the 7th to the 48th hour. The subjects worked with the Kellogg Dynamometer and performed 4 tests at any one trial, with each hand in pronated or supinated position.

The results for studies (1) and (2) are presented in tabulated and graphic form and in a detailed summary at the end. In study (3) a general falling-off in strength was observed over the 42-hour test period. Yet it was also possible for subjects to marshall sufficient reserve strength, for the single maximum efforts that were called for in this research, to attain values as high as in the initial test. In a number of instances final scores were actually better than the first, but the general pattern was a decline during the latter stages of the test period.

The author provides a massive reporting of detailed measurements in a lengthy series of graphs and tables. The results are not statistically handled and are presented only as arithmetic comparisons between various averages, percentages, and maximum and minimum scores. In test situation (3), the methodology is even more inadequate. There is no control group to compare with the sleep-deprived subjects. This makes any inference about the relationship between fatigue and muscle strength of limited value, since there is no way to distinguish the effects of practice from the effects of fatigue, even granting the initial strength measurement as a kind of control. The sample is small (6 subjects), and results are reported separately for individual cases. Again, no statistical analysis is performed on the data either for individuals or for the sample group as awhole.

88

Hussman, T. A., A Critical Evaluation of Four Indicators of Behavior Decrement, College Park, Maryland University, DDC AD #31 301 (1952).

Abstract:

Four potential behavior decrement indices—steadiness, blind steadiness, tapping, and CFF—were used in order to determine: (1) the effects of fatigue and anxiety on subjects; (2) if these indices would serve as valid predictors of behavior; (3) if these indices were consistent or varying in an individual; (4) if the variables changed with other known factors in a testing situation; and (5) the interrelationships existing among the several variables. Twenty-four male undergraduates —12 experienced boxers and 12 novices, aged 19–25—served as subjects. Each subject was measured on the battery of the four tests three times after each of one of four experimental conditions: (1) at rest; (2) before three rounds of boxing with no previous exercise; (3) after three rounds of boxing with a punching bag with no expected ring combat; (4) after fighting three rounds with an opponent. The subjects were randomly assigned to the experimental conditions except for the initial trial which was always at rest to allow the experimenter to explain the the procedure. A pilot run with 15 subjects who were not included in the experimental 24 was conducted in order to standardize procedure. No subject was administered the test battery more than twice during any one day.

Results: (1) Steadiness was determined to be the most promising behavior decrement indicator for assessing fatigue effects ($p < 0.001$). (2) The blind steadiness score changed significantly ($p<0.05$) as a result of anxiety and fatigue. The changes produced were large enough to allow prediction with the test. (3) The blind steadiness time score was found to be unreliable as a test or indicator. (4) CCF thresholds changed significantly ($p <0.001$) as a result of anxiety, but the change was too small to be useful for prediction. (5) Tapping was found to be unreliable. Significant changes ($p <0.05$) were found in scores as a result of fatigue and anxiety, however, the author felt that learning was responsible for this. (6) It was found that the steadiness and blind steadiness tests were both highly correlated indices, and it was concluded that they were the most useful predictors of decrements produced by fatigue.

This is an excellent study. It contains very thorough methodology, development and discussion sections. Extensive statistics were employed, including such measures as analysis of variance. product-moment correlations, and Bartlett's Test of Homogeneity of Variances.

89

Jackson, K. F., Aircrew Fatigue in Long Range Maritime Reconnaissance: 2. Pilot Performance, Farnborough (England), RAF Institute of Aviation Medicine, FPRC 907.2, DDC AD 125230 (1956).

Abstract:

The performance of ten pilots was investigated by making continuous records of the altitude and heading of their aircraft at chosen times during a series in which each pilot undertook four 15-hour flights on alternate nights. The records, which concerned straight and level flying only, were examined—a 10-minute section at a time—for both extent and variability of error, thus providing four measures for each 10-minute record. Turbulence was recorded in terms of vertical accelerations. Each pilot operated the controls for approximately four 2-hour watches in each flight.

It was observed: (1) Performance in maintaining a constant heading deteriorated during 40 minutes of continuous work. (2) Performance in both heading and altitude deteriorated during the first three of pilots' watches and partially recovered in the fourth. (3) In their first two watches, pilots tended to fly more accurately and consistently in rough air than in calm air, but in the last two watches they were adversely affected by turbulent conditions. (4) Performance did not change appreciably from flight to flight during the four 15-hour flights. (5) The deteriorations which were observed could not be accounted for by increased turbulence.

It must be noted in reference to (2) that the first and fourth watches were in daylight and the others at night. It is unfortunate in this study that the natural diurnal variation in the capacity for work could not be distinguished from the effect of continued work. However, the differences which existed between the scores for the first and last watches were, according to the author, rather large to be explained entirely by daylight or night conditions. Further experimentation is obviously necessary to eliminate this interfering variable.

A full array of graphs, tables, and statistical information is appended to the text.

90

Jhurkov, E. K., and Zaharianz, J. Z., Electrophysiological data on certain mechanisms of overcoming fatigue, Fiziologicheskii Zhurnal SSSR imeni Secheneva **46**, 819–827 (1960).

Abstract:

Changes in the activity of the biceps and triceps brachii and alterations in their innervation were studied during the development of a fatigue state by electromyographic means. Fatigue was produced from the prolonged supporting of a load (from 2 to 30 kg) on the arm bent at the elbow or from a number of liftings and lowerings of this load by bending and extending the arm at the elbow joint. A mechanogram was recorded simultaneously, and the subject's respiration and cutaneous autonomic reactions were observed. Subjective reports by the subject were also recorded as to the difficulty of the work performed. The authors performed some of the experiments on themselves as well, in order to improve the subjective evaluation of the developing fatigue.

At a certain point in each experiment the work of supporting or lifting the load appeared subjectively to be very difficult. At this same time changes in the character of respiration, a reddening of the skin, sweating, and irradiation of excitation on some of the other muscles were observed. However, due possibly to the effect of motivation, the high standard of work performed before this point may still be maintained for a long time. Along with this there appear typical changes in the EMG: the value of the action potentials grows, the summary bioelectric activity increases, and synchronization of the activity of muscle fibers develops.

The authors conclude that the maintenance of the initial high standard of performance in spite of the developing fatigue is achieved with the aid of a growing quantity of the neuromotor units involved and the synchronization of their activity.

This is a very good study. The report includes reproductions of several electromyograms.

91

Johnson, Laverne C., and Corah, Norman L., Racial differences in skin resistance, Science **139**, 766–767 (1963).

Abstract:

While investigating other problems, the authors, in separate laboratories and using different age subjects and recording techniques, noted that the basal skin resistance of Negroes is uniformly higher than that of comparable white subjects. One study was of 65 white boys, 22 Negro boys, 55 white girls. and 32 Negro girls, all between the ages of 83 and 92 months. Each child's skin resistance level was taken at five, two-minute intervals over a ten-minute resting period in bed in the laboratory. Zinc electrodes, 15 mm in diameter, were attached with zinc sulfate jelly to the first and third fingers of the right hand. Mean Negro skin resistance was approximately 40,000 ohms above that of the white children. Analysis of variance indicated that race was significant at $p < 0.001$, and sex at $p = 0.025$.

The second experiment examined 16 Negro men and 5 women, mean age 23.05 years; and 16 white men and 5 women, mean age 22.90. Ages ranged from 18 to 39. Six EEG channels, heart rate, respiration rate, and skin and room temperatures were recorded in addition to GSR. Recordings were made after a 15-minute pre-examination period, and a five-second doorbell buzzer located behind the subject was used as a stimulus to autonomic reactivity. Frequency of stimulus presentation and duration of test period were not stated. Palm-to-palm GSR recordings were made with 2-cm diameter electrodes encased in a plastic cup and attached with agar zinc sulfate paste. The mean skin resistance level for the white subjects was 171,000 ohms, as against 373,000 for the Negro subjects, a difference significant at $p < 0.001$. There were no significant differences in EEG amplitude, heart rate, respiration rate, skin temperature, spontaneous GSR activity. diastolic and systolic blood pressure, manifest anxiety, or any of the autonomic responses to the buzzer.

Skin color does not appear to be the important factor, as the melanin-producing cells are in the stratum malpighii of the epidermis, not the stratum corneum where 80 percent of the skin resistance is supposed to be. The authors hypothesized that the thicker stratum corneum of the Negro may be the determining factor or that there may be a difference in the number of active eccrine sweat glands—possibilities presently under investigation.

92

Kahneman, Daniel, Beatty, Jackson, and Pollack, Irwin. Perceptual deficit during a mental task, Science **157** (3785), 218–219 (1967).

Abstract:

This experiment tested the prediction that, if intense mental activity hinders perception, perceptual efficiency should vary with the pupillary response. Seventeen student volunteers performed two tasks simultaneously: a digit transformation task and a detection task. The subject heard a string of four digits presented by tape recorder at the rate of one digit per second, and responded at the same rate, after a pause of one second, by adding 1 to each digit he had heard. At the same time the subject monitored a Binaview display which flashed letters at a rate of five letters per second. The subject reported after each trial if the letter K had been among those presented. He was paid 2¢ for each string of digits transformed correctly and 1 if he correctly reported either the occurrence or the absence of a K in the trial and penalized 5¢ for reporting that a K had been shown when it had not. Photographs of the pupils of nine subjects were taken on infrared film by infrared strobe light. In 100 trials, both the transformation and detection tasks were required, although in 25 of these no K was presented. There were 20 transformation-only trials, before which the subject was informed that the letter K would not appear, and 20 detection-only trials, on which the transformation task was made very simple.

The average pupillary response curve, counting only those trials on which the response had been fully correct, was characterized by a steady dilation of the pupil (from 5.3 to 5.7 mm) through the listening phase of the task and the first part of the report, then a decrease in size. The dilation was smallest in the detection-only condition ($p < 0.01$), but there was no consistent difference between the curves for the two conditions of double task and transformation only. The rate of constriction of the pupil on the final two seconds of the task appeared to depend on the level of illumination to which the eye was exposed. The two activities of detection and transformation mutually interfered with each other. The ability to detect signals varied continuously during the eight seconds of the task, in parallel with the pupillary-response indicator of the processing load. The authors conclude that the subjects were to some degree functionally blind when they were engaged in thought.

93

Kienc, L., Association experiment and time perception as the fatigue index, Pracovni Lekarstvi **12**, 538–541 (1960).

Abstract:

The authors investigated the functional changes of the central nervous system during a working load by the method of time estimation (in 85 individuals) and by means of the association experiment (in 48 individuals). Neither method gave satisfactory results under the experimental set-up used and could be used as a reliable test for assessing changes due to fatigue or for assessing the efficiency of our experimental subjects. The method of time estimation seem to be a more sensitive indicator; the interpretation of results is, however, so far very difficult.

This is a good work. The results are tabulated. (Authors' Summary.)

94

Kikolov, A. I., Changes of physiological functions in persons working at control panels, Gigiena i Sanitarija, (Moscow) **25**, No. 1, 34–40 (1960).

Abstract:

The physiological functions have been studied in groups of individuals working at control nanels of a television studio and of a subway. Such activity may be regarded as a model of strenuous intellectual work.

The changes of physiological functions observed in the operators of these groups included increased initial lability with subsequent drop towards the end of the work hours, a rise of the sugar level in the blood and in the arterial blood pressure, lengthening of the latent period and a decrease in the intensity of conditioned reflexes towards the end of the work.

The results of these investigations served as a physiological background for a differential approach to the physiological determination of regimens of work and rest for both groups of operators. (Author's Abstract.)

This is a good study of some of the physiological consequences of work involving little physical effort.

95

Klein, S. J., Relation of muscle action potentials variously induced to breakdown of work, Perceptual and Motor Skills **12**, 131–141 (1961).

Abstract:

The object of this study was to determine whether the relationships between muscle action potentials (MAP) and breakdown of work were dependent upon how MAP were induced. Thirteen males lifted a 2200-g ergographic weight to a reference line (77mm from S) at varying rates (30 or 40 lifts per minute) and under varying thermal stimuli (1° C. or 33° C. immersion in water). The task procedure was to lift the weight 16 times, rest four minutes, immerse the working hand in one of the thermal conditions, wait two minutes, and proceed to lift the weight at the determined rate until exhaustion. The rates of lift were regulated by a metronome; speed was recorded on a variable speed kymograph; and MAP were photographically recorded through impulses from an electrode in the working arm. MAP were classified in one of two ways: (1) as direct potentials induced during the task; or (2) as residual potentials of those previously induced by the cold-warm stimulus.

Results: (1) Faster work rates showed significantly higher MAP. (2) MAP were higher after cold exposure than warm. (3) An increase in MAP was associated with an increase in breakdown of work, independent of how induced.

This is an excellent study including thorough development, explanation and statistical analysis.

96

Knowlton, G. C., Bennett, R. L., & McClure, R.. Electromyography of fatigue, Archives of Physical Medicine **32**, 648–652 (1951).

Abstract:

The purpose of this study was to present the results of observations made on control muscles during work to subjective fatigue with various loads and at several work rates. The test muscle used was the biceps brachialis. Six subjects performed a task consisting of lifting a handheld weight (5–25 lb) at a given rate to the point of subjective fatigue. Action potential amplitude and voltage were recorded and analyzed for the number of contractions from 20%–100% fatigue. Two-day rest intervals were allowed between testing with a varying weight. The results indicated that: (1) In terms of absolute voltage, the initial potentials increased with increased load. (2) Rate and extent increased up to a maximum load and then decreased with heavier loads. (3) The action potential amplitude was greater at fatigue than at the initial contractions. (4) The better the muscle grade the closer the response was to that of the control muscles. (5) Certain grade muscles gave a reversed voltage response, in that the action potential voltage decreased during repetitive contractions. This type of response was associated with muscles which later decreased during a functional exercise program.

This is an adequate study, but lacks statistical treatment.

97

Kramer, Edward F., Jr., Hale, Henry B., and Williams, Edgar W., Physiologic Effects of an 18-Hour Flight in F–4C Aircraft, Brooks AFB, Texas, School of Aerospace Medicine, SAM–TR–66–59, DDC AD #636 911 (1966).

Abstract:

Eight pilots were tested for adrenocortical, sympathoadrenal, and metabolic activities by means of urinalysis after 18-hours of flight to determine physiologic reactions to a moderately fatiguing flight. Pre-flight control was maintained by putting the men on a low-residue diet three days before testing and by insuring maximum rest prior to the flight period. To offset fatigue, 5 mg of dextroamphetamine was issued at the 9th, 12th and 16th hours of flight. Urine specimens were collected after return and were analyzed for 17-hydroxycorticosteroids, norepinephrine, epinephrine, magnesium, phosphorus, potassium, sodium, urea, uric acid, and creatinine. Control specimens were collected two weeks later on a nonflying day. In addition, results were compared with nonflying personnel under fundamentally similar conditions.

This study supported the belief that flying experience, flying difficulty and flight duration in part determine the character of physiologic responses to flight. The flight-induced physiologic changes included: (1) increased 17-hydroxycorticosteroids, which implied adrenocortical stimulation, and (2) decreased excretion of uric acid, potassium, and urine, which suggested metabolic depression. Additional results indicated that low-grade physiologic displacement was associated with low-grade fatigue symptoms. but not enough research has been done on this to ascertain if they are interdependent.

This was a well-controlled experiment, containing adequate statistical analysis of the results.

98

Kreider, Marlin B., Dee, Thomas and Vaughan, John A. Effect of Reduced Ration and Method of Load Carrying on Physical Fitness and Energy Expenditure of Small Groups of Men Operating on the Greenland Icecap, Natick, Mass., Quartermaster Research and Engineering Center, Tech. Rept. EP–160. DDC AD #430,067 (1961).

Abstract:

Nineteen young male soldiers from Fort Lee, Va., participated in two ten-day treks, separated by a seven-day rest period, on the Greenland icecap at 7,000′ altitude. The subjects hiked eight miles each day divided into two major groups: one living on full rations (about 4800 calories); the other on a ration reduced by about 40 per cent. Both groups were further subdivided according to methods of load carrying: on a two-man pulled sled, and divided between a sled and back pack. The method of load transport was alternated for each man during the different halves of each ten-day test period, and the ration regimen was alternated for the two periods. The subjects were on the icecap for about 26 days before the experimental periods began.

Physical fitness was measured by the Harvard step test before and after each experimental period, and this was compared with performance on a treadmill after return to near sea level. Subjects also ranked each other by subjective estimates of fitness, and were ranked also by the experimenters. A mild step test called the Altitude step test compared metabolic and respiratory requirements at altitude with those at sea level. Volume of inspired air was measured by a small turbine wheel geared to a revolution counter and worn in a standard gas mask. The volume of oxygen inspired was computed from the mass of air passing through the meter. Body weights were measured frequently.

Body weights fell an average of 1.6 kg in Period I and 1.8 kg in Period II on the full ration; and 2.7 kg and 3.8 kg, respectively, on the reduced rations. Physical endurance, as measured by the Harvard step test, improved for both ration conditions and over both experimental periods. Fitness tests and subjective evaluations were compared by Spearman's coefficient of correlation, with the highest correlations obtaining between the Harvard step test and investigator evaluation of endurance, and between investigator evaluation of endurance and subject evaluation of ability to survive on ice. The treadmill test and subjective evaluations did not correlate highly with the Harvard step test. Volume of inspired oxygen decreased for both ration groups, but dropped lower for the men on the reduced ration, even when plotted by body weight. Oxygen cost was greater when carrying a load on the back and on a sled than when the load was entirely on the sled. Respiratory volume (STPD) increased about 8% at 7,000' above that at sea level. Volume of inspired air during the mild step test remained higher for at least 12 days after return to sea level, but dropped to normal at 19 days.

This is an excellent experiment. It is unfortunate that on-the-job modifications had to be made to the air-flow meters, restricting their use to the second test period. It may be wished that such measures as pulse rate and body temperature had been used.

99

Laporte, W., The influence of a gymnastic pause upon recovery following post office work, Ergonomics **9** (6), 501–506 (1966).

Abstract:

This study compared the dissipation of fatigue after a gymnastic pause and after a passive pause both introduced during the performance of psycho-nervous work. Two groups of 40 women in the Post-Cheque Office in Brussels were used as subjects. The average age of the control (passive) group was 25 ± 0.31 years; of the experimental (gymnastic) 25 ± 0.28 years. A 10 minute pause was inserted in the afternoon schedule where the critical point of fatigue occurred—about 3:00. Every day, immediately before and after the work pause, two members of each group were given a test battery consisting of four tests which measured different aspects of fatigue: (1) flicker fusion frequency test; (2) Wechsler's digit-symbol test; (3) hand dynamometer test; (4) Piéron's dynamic tremor test. The gymnastic rest period consisted of exercises for the legs, arms, neck, and trunk; and were devised for psychological relaxation, relief of muscle strain, and promotion of muscle tone. Music accompanied the exercise, with the lesson changed each week. The passive group could not leave the premises but were allowed to listen to the music used by the experimental group.

Results: (1) The experimental group performed better than the control on all tests. (2) A highly significant difference ($p<0.001$) was noted for the flicker fusion frequency and digit-symbol tests. (3) It was concluded that the light gymnastic exercises were superior to a passive pause, favorably influencing the measured sensory-motor and intellectual faculties.

This is a good study, exhibiting the required methodology and statistical analyses.

100

Lehmkuhl, D., and Imig, C. J., Measurement of Maximal Blood Flow Following A Standardized Fatiguing Exercise for Evaluation of the Functional Capacity of the Peripheral Circulation, American Journal of Physical Medicine **40**, 146–157 (1961).

Abstract:

A local, rhythmic exercise carried out to apparent fatigue constitutes an adequate stress procedure for determining the capacity of blood vessels in skeletal muscle of the extremities to undergo vasodilation. 75 healthy college students between the ages of 17 and 40 years exercised the plantar flexor muscles of the foot while in a supine position in a 7-inch long water-filled (34–32° C.) plethysmograph. The rate of swelling of the tissues following venous occlusion was measured by recording increases in hydrostatic pressure by means of a pressure transducer. Blood flow was measured several times 2–3 min before exercise, within 10 sec following exercise, and at intervals until 22 min after exercise. The highest blood flow recorded during the first minute after exercise was regarded as the peak flow. Paired comparisons were made with student's t test, and the null hypothesis was rejected at the 5% level. Exercise consisted of depressing a foot pedal with the ball of the foot once per second, alternately lifting weights, until the subject could no longer depress the pedal. A pilot study using different weights (8.6 to 15.5 kg. resistance) with consequent wide differences in time to complete muscle fatigue (1.0 to 31.0 min) indicated that the maximal post-exercise peak blood flow would be reached when complete fatigue set in from 1 to 5 min afer the start of the exercise. Another study was conducted on 16 students to determine if previous muscle activity or alterations in the pre-exercise blood flow level would influence the maximum level of post-exercise hyperemia. Two series were run, with 2 exercise periods 8 min. and 25 min. apart respectively, and no significant difference in post-exercise blood flow peak was found between the second exercise of each of these series and that obtained when the exercise was preceded by rest. Four fatiguing exercises performed by each of 6 subjects showed that local application of heat and cold (22° C.–42° C.) to the calf affected the resting blood flow but not the peak flow. No significant differences were found between peak flow of the right and the left legs of 10 subjects, or in tests 1 week apart on 22 subjects. A final study was done with 53 subjects 17–40 years old (M = 24.3), who reached rapid fatigue with weights of 9.8 to 15.5 kg. (M = 12.8 kg.). The mean post-exercise peak blood flow was 27.4 ml per 100 ml per min. with a range of 17.4 to 56.1. Inspection of the individual data revealed no apparent relationship between the amount of work done in achieving fatigue, body surface area, or general physical condition, and the maximum post-exercise blood flow. This procedure should be a satisfactory standardized stress for evaluating the functional status of peripheral circulation. This is an excellent, well planned and controlled study—class one.

101

Lowenstein, O., Feinberg, R., and Loewenfeld, I. E., Pupillary movements during acute and chronic fatigue, Investigative Opthalmology **2**, 38–57 (April, 1963).

Abstract:

Spontaneous pupillary movements in darkness were recorded: (1) in healthy subjects of different ages when they were rested and/or when fatigued, (2) in chronically tired subjects without known neurological defects, and (3) in patients with various neurological lesions. Local or systemic drugs were used in some of the experiments. Subjects were seated in a chair in complete darkness, with eyes fixated on a red spot (size not given) 6 feet in front and 15° above the eye level of the patient. Records of pupil diameter variations during time were recorded by the authors' infrared-sensitive electronic pupillograph. The number of subjects in the various states tested is not given. It was found that when the subject is alert the pupils are large and quiet in darkness (for periods of up to several hours), but when the subject is "tired", the pupils oscillate in diameter. Waves of spontaneous pupillary contraction and dilation accompany periods of increasing sleepiness and spontaneous arousal until, at the moment immediately preceding sleep, the pupils become very small. The mechanism of these movements was analyzed and a simple test described which allows the objective determination of the degree of acute fatigue in a given subject at a given time. Since not enough data are presented about the number and nature of subjects, and since no statistical analysis is presented, this must be rated class 2.

102

Lundervold, Arne, Electromyographic investigations during typewriting, Ergonomics **1** (3), 226–233 (1957).

Abstract:

This report contained the results of studies designed to

determine to what magnitude muscles were used in a single one-key tapping task on a typewriter. Electromyograms recorded all muscle contractions and their durations. This electrical activity was recorded by means of a two-channel differential electromyograph and an eight-channel electroencephalograph. Both needle and surface electrodes were used.

The following findings were cited in this report:

(1) A constant electric oscillation was maintained in experienced typists working at their own pace for long durations of time. However, when they were required to speed up, oscillation amplitude and rate increased not only in those muscles directly involved in the task, but in other muscles as well (leg muscles for example). Upon reaching a state of fatigue (which occurred faster than when working at their own pace), the subjects slowed down, but the muscle action potentials continued to increase. It was concluded from this that when required to work at a set pace, typists become fatigued faster and need short rest breaks.

(2) In a similar experiment using five women and ten men who had never used a typewriter, the same results were found, in addition to the fact that each individual muscle recorded contracted more forcibly and for a longer time. It was concluded that experienced typists performed at a more relaxed and efficient level than the novices.

(3) Studies in which room temperature was varied (68° −59° F.), illumination intensity varied (200 lux-10 lux), and noise level was varied to about 90 decibels, showed that muscles contracted more vigorously and more muscles were used under conditions of chilliness, loud noise, and bad lighting.

(4) The more typists concentrate on their work, the more MAPs there are. When attention was diverted, MAPs reduced.

(5) Pulse, respiration rate, and sweat gland activity all increased with increased MAPs and diminished in the same fashion.

(6) MAPs were less when the typist worked in a relaxed, well-balanced position rather than a tense, upright position.

(7) Experienced typists will perform best when seated in a relaxed, well-balanced position (or with a back rest), with the machines placed in front of them at a distance such that the upper arm could hang freely down when the person was typing. The typists worked best in a comfortable environment (i.e., well-lighted, not too noisy or cold) and at a high set speed with short rest periods.

This report summerized the studies that have been done with typewriters and MAPs. The author presented the individual studies very briefly and compactly. No statistics were presented, and it can be only presumed that the original studies presented sufficient support to accept the stated conclusions.

103

Lybrand, William A., An Exploratory Investigation of Tasks of Perceptual Organization as Potential Indicators of Behavior Decrement, College Park, Univ. of Maryland. AD #31,310 (1952).

Abstract:

This is an exploratory investigation designed to determine the effects of variations in activity and sleep deprivation on perceptual organization tasks (the Kohs Block Design, the Perception of Hidden Figures and the Müller-Lyer Illusion). Forty-eight males were divided into four groups and were tested with these tasks after participation in one of the following conditions: (1) at rest; (2) after a regular night's sleep and a five mile march with a 40 lb. back pack; (3) after the loss of one night's regular sleep; (4) after the loss of one night's regular sleep and a five mile march with a 40 lb. back pack. Pre-experimental measurements on the Cards section of the PMA Space Battery and the Perception of Hidden Figures were made for each S after a regular night's sleep. The next day, conditions 1 and 2 were run, with 3 and 4 the following day.

Results: (1) It appeared that conditions assumed to induce general systemic fatigue differentially affect performance on certain tasks of perceptual organization. (2) Fatigue induced by marching produced more efficient performance on the Kohs Block Designs. (3) Fatigue induced by sleep loss produced less efficient performance on the Perception of the Hidden Figures and the Kohs Block Designs. (4) Fatigue produced by the interaction of sleep deprivation and marching differentially affected performance on the Kohs Block Designs. (5) Kohs Block Design and the Perception of Hidden Figures was tentatively accepted as a useful indicator of behavior decrements in situations involving perceptual organization. (6) Performance in behavioral situations involving perceptual organization as a basic factor was more efficient after mild physical activity and less efficient after sleep deprivation.

This is an excellent study. Statistical treatment included an analysis of covariance for results on the Kohs Block Designs and the Perception of Hidden Figures; and an analysis of variance for the Müller-Lyer Illusion task.

104

Mack, Pauline Beery, and Dixon, M. S., A Study of the relation between ingestion of frozen orange juice and resistance to fatigue, Amer. Practitioner and Digest of Treatment **6** (4), 584–589 (1955).

Abstract:

A previous interview survey by the senior author of this study determined that the major reason of 500 subjects for dranking between-meal beverages was the belief that such beverages gave them resistance to fatigue. This experiment investigates the relation between orange juice and fatigue resistance, as measured by test performance.

One hundred twenty-four children, ranging in age from 10 to 19 years, participated in five tests designed to measure some aspects of fatigue resistance, as follows: (a) change in hand strength after 20 repeated tests of each hand using a manometer (percentage change in pounds); (b) endurance in push-up and sit-up tests (percentage change in the number of push-ups and sit-ups the subject could accomplish); (c) fatigue in pulse-ratio or step test (percentage change in pulse rate after 30 steps per minute for five minutes); (d) speed with which two standard manual tests could be completed accurately (percentage change in time required to complete Minnesota Form Board tests of two levels of accuracy). The tests were given in the early morning, twelve hours after the last meal; the first of each pair of tests being administered initially, and the second exacly fifteen minutes after the ingestion of orange juice (the ordinary mixture of three parts water to one part frozen juice) or a control beverage having no nutritional or caloric value (artificially colored water). Each subject was tested on ten separate mornings, receiving only one of the five tests and one of the two beverages on any one morning, eventually receiving all ten combinations of tests and beverages.

The results: (a) On the average, the change in response in the respective tests after ingestion of orange juice exceeded the change following the control beverage, except in the case of the manuometer test, where there was no significant difference in average response. (b) The change in endurance trials following the orange juice surpassed the change following the control beverage by a significant amount (p 0.01) in each case. (c) The response differences in the pulse-ratio tests favored the orange juice, but not in a statistically significant amount. (d) The average time change in the Minnesota Form Board tests was more favorable for the orange juice than for the control drink by a difference significant at the 0.05 level.

Other experimentation also reported showed: (a) When twenty-five children ingested orange juice of double the recommended concentration (1.5 parts water to one part concentrate) in comparison with the same control liquid in four of the above tests (omitting the sit-up test), average results favoring the orange juice were obained in all cases. The differences were statistically significant ($p < 0.01$ or 0.05) for all tests except the manuometer. The percentage differences tended to be wider for all tests with the double concentration than with the single concentration. (b) When four tests were presented to twenty-five adults, ranging from 20 to 57 years, using the double concentration of juice, the results favored the orange juice above the control drink for the push-up, the Minnesota Form Board, and the hand grip tests, with statistically significant differences in the former two tests. (c) The tests

were repeated for seven children with orange juice of both concentrations in comparison with an artificially colored drink of water and sugar of approximately the same concentration as the sugar in the orange juice. The findings indicated that the favorable results depended chiefly on the sugar content of the orange juice. However, it was indicated (with results not statistically significant) that the endurance tests may have been dependent upon some other factor in the orange juice in addition to the sugar.

This was a well controlled experiment, adequately and statistically analyzed, demonstrating one aspect of the effect of nutrition upon fatigue. One minor suggestion may be made regarding methodology. All subjects were given the same sequence of tests, always receiving the test with the orange juice before that same test with the control drink. Future research should vary the sequence of tests, to mitigate uneven learning factors.

105

Mateyev, D., Muscle fatigue, Fiziologicheskii Zhurnal SSSR imeni I. M. Secheneva **47**, 557–563 (1961).

Abstract:

Is the origin of muscle fatigue peripheral or central? Merton (1954, 1956), studying static work contraction of adductor pollicis muscle, concluded that it is peripherial and developed in the active muscle itself. Mateyev here rejects this conclusion. Merton had stimulated a fatigued muscle and got no additional contraction. Mateyev says it is wrong to assume that additional simulation, delivered in the presence of maximum voluntary static muscle contraction, leads to additional contraction. Merton failed to consider the lability of nerve cells, nerve-muscle junctions, and the muscle fiber itself. Merton used no control experiment. Reid (1928), using a Mosso ergograph, concluded that muscle fatigue was of central origin, as the contractile power of the muscle was found not to be exhausted when the voluntary work had been performed to a standstill. Reid found additional contraction occurred from a weak electrical stimulation. Merton had used a strong stimulus. The lability of the nerve cells is lower than that of the muscle, and this places a limit on voluntary effort.

106

Mateyev, D., and Georgiev, V., On relations between fatigue and type of higher nervous activity, Fiziologicheskii Zhurnal SSSR imeni Secheneva, I. T. **46** 141–147 (1960).

Abstract:

Tracings obtained by means of a Mosso ergograph are shown to be specific for each subject, individual features being recorded with great regularity. The ergogram is considered as a graphic expression of the manner in which transition between processes of excitation and inhibition is effected during exercise. Individual specificity displayed by the form of this transition depends on the type of nervous activity. Ergograms of a convex shape are shown to be characteristic of strong types of nervous activity (sanguine, choloric, phlegmatic), tracings of a concave shape being obtained in subjects of an inhibitory type. The ergographic method of Mosso may serve for the investigation of types in humans. (Authors' Abstract.)

A good study. The results are tabulated.

107

Matoush, LeRoy O., et al., Physiological and Biochemical Evaluation of Potential Anti-Fatigue Drugs. II. The Effects of Aspartic Acid Salts (Mg and K) on the Performance of Rats and Dogs, Denver, U.S. Army Medical Research and Nutrition Lab., Report #274, DDC AD #400,721 (1963).

Abstract:

Dogs (N=24) and rats (N=132 males, 12 females) performed single and double swim tests in order to assess Spartase as a means of increasing endurance in animals. The rats swam in a large glass jar, 12 inches in diameter and 24 inches deep with the water level being maintained at 18 inches and at a temperature of either 25° C. or 17° C. Turbulence was provided to prevent the rats from floating. The dogs swam in a five foot square, five foot deep tank with smooth stainless steel sides. There was a total of five experiments—four using Sprague-Dawley rats and one using dogs. Experimental design was as follows:

(a) Experiment 1 (single-swim test): 40 male rats were randomly assigned to two groups: one received no Spartase before the first swim and the other ingested 0.5 g Spartase prior to the initial swim. Water temperature was maintained at 25° C. The task consisted of swimming until exhaustion, recovery, and then swimming until exhaustion again. The group that had no therapy was given a dosage of Spartase 30 minutes before the last swim. Each animal served as his own control.

(b) Experiment 2 (single-swim test): Same design as experiment 1, except that the water temperature was 17° C.

(c) Experiment 3 (single-swim test): The same design was followed as experiment 1, using four dogs; drug dosage was 2 tablets/dog 0.5 g Spartase/tablet. Rectal temperatures were recorded before, during, and after each swim. Water temperature was 17° C.

(d) Experiment 4 (Long-term, single-swim test): Forty male rats were divided into two groups: group 1 received no therapy, and group two, 500 mg of Spartase. Water temperature was kept at 25° C. Spartase therapy was administered 5 days on each of five weeks. All animals swam twice a week, the Spartase being administered to group two 30 minutes prior to the swim. A 9 g weight was attached around all animals' necks to reduce swim time. Week 6 was used as a recovery period.

(e) Experiment 5 (double swim test): Twenty-four rats (12 male and 12 female) were divided into two groups: no therapy and Spartase (0.5 g). The test ran 6 weeks: one week control, 4 weeks therapy, and one week recovery. Therapy was administered in the afternoon, seven days a week. A second swim was initiated 2½ hours after the first swim, with treatment after the first swim. The rats swam twice a week with a weight equal to 3% of their body weight. Water temperature was held constant at 25° C.

Results: (a) There was no significant difference ($p < 0.05$) between control and Spartase groups in any of the experiments. (b) Swimming times of rats at 17° C. were considerably shorter than at 25° C. (c) It was concluded that under the conditions of this experiment, no significant effect on swimming times of rats or dogs could be attributed to the ingestion of Spartase.

This is a well-organized study and includes good statistical analysis of the results. The study is of significant importance, as it disagrees with some previous work which stated that Spartase delayed the onset of fatigue; but it is in agreement with studies which state that Spartase has no effect in delaying fatigue onset. It would appear that the value of Spartase is still in question and needs further research.

108

McDonald, David G., Johnson, Laverne C., and Hord, David J., Habituation of the Orienting Response in Alert and Drowsy Subjects, San Diego, U.S. Navy Medical Neuropsychiatric Research Unit, Report No. 63–17, DDC AD No. 429,835 (1963).

Abstract:

Two similar experiments were conducted to investigate psychophysiological habituation of the orienting response to novel stimuli by alert and drowsy subjects. Subjects were seated in a semi-soundproof, darkened room and were given a preliminary explanation of the procedures while the recording electrodes were being applied. All subjects were instructed to sit quietly with eyes closed, but to remain awake. The experimenter then left the room, and recording began after a five- to ten-minute period required to adjust and calibrate the recording. All psychophysiological measures were recorded continuously during the session on a 12-channel dynograph. Four channels of EEG were recorded, although only two of these (right and left occipital) were used to monitor the depth of sleep. Also measured were: (1) skin resistance (GSR); (2) heart rate (HR), by a cardiotachometer; (3) finger vasocon-

striction, with a photocrystal plethysmograph attached to the left index finger; (4) respiration, by a strain-gauge belt around the chest; and (5) finger temperature, obtained from a thermistor taped to the left middle finger. Two measures of GSR were used: the response to the stimulus presentation, and the number of "spontaneous" or "nonspecific" GSR's occurring between each trial. The measure of HR response was the difference between the fastest beat during beats 2–6 after stimulus onset, minus the slowest beat during beats 7–20 after stimulus onset. Subjects who showed EEG evidence of sleep on any trial were classified as drowsy, and the remainder of subjects were classified as alert.

Experiment I—30 male Caucasian students in the U.S. Naval Hospital Corps School, San Diego, served as subjects. Their ages ranged from 17 to 27 years, with an average of 19.3. After five minutes of resting recording, each subject received a series of ten presentations of a relatively loud doorbell-type buzzer; each presentation lasting for three seconds, with intertrial intervals randomly varying from 30 to 60 seconds. Nineteen of the 30 subjects showed EEG evidence of sleep on at least one trial. Depth of sleep increased during the testing, but was not usually marked. No significant differences were found between the alert and drowsy groups in age, MMPI K scores, Taylor Manifest Anxiety Scale scores, self-ratings of adjustment and anxiety, or on the physiological measures made during the five-minute period prior to the first buzzer. Testing for habituation by comparing the first and last three trials indicated that, in general, the alert group showed significant adaptation to the stimulus, whereas the drowsy group did so only in the measures of GSR and finger vasoconstriction. Of the comparisons between group means for 10 trials, only spontaneous GSR and HR response comparisons approached significance (two-tailed t's had a probability of 0.10 in each case). Respiration response data showed neither differences between groups nor systematic trends over trials.

Experiment II—subjects were 69 Caucasian males from the same source as in I. Their mean age was 19.1 with a range from 17 to 24. All preliminary procedures were the same as in I, except that the subjects were instructed to tap on a microphone taped to the arm of the chair once every 30 seconds (by their estimation) and 3 times every 15 minutes. The stimulus used in this experiment was a 10-second duration 500 hz tone at 75–80 dB, presented 10 times, 60–90 seconds apart. Thirty-two subjects were classified by EEG as being drowsy, leaving 37 alert. No psychological measures were available to compare the drowsy and alert subjects in this experiment. As in Experiment I, the alert group showed significant trends for finger temperature. Contrary to the findings in Experiment I, the drowsy group here showed a significant ($p = 0.02$) decrease in the number of spontaneous GSR's. One-tailed t-tests between group means were significant at the 0.05 level for spontaneous GSR, HR, and finger plethysmograph, but not for GSR.

Although the authors rule out the "Law of Initial Value," the amount of sinus arrhythmia, and any differential startle value of the stimulus for drowsy subjects as explanations for the results; they do not offer an hypothesis for the between-group differences. No mention of the effects of having the subjects in Experiment II estimate time passage was made in the report.

109

McFarland, Ross A., The Application of Environmental Stress Studies to an Understanding of Operational Fatigue, presented at the XVth International Congress of Occupational Health, Vienna, Austria (1966).

Abstract:

Operational fatigue is discussed in terms of work output in the presence of various environmental stresses, rather than considering subjective, psychological fatigue or physiological impairment. The author proposes that researchers apply to the study of operational fatigue those methods which have been used previously to study environmental stresses such as vibration, noise, high altitude, temperature extremes, and work-cycles. Two factors which can explain many of the inconsistencies reported in fatigue studies are examined:

(1) The masking of fatigue effects often caused by the subject's "trying harder." Tests need to be developed to either overcome the effect of increased motivation or detect the increased effort at a task.

(2) Degree of task difficulty. This influences the amount of performance decrement which will be observed under various stresses.

Techniques recently developed through information theory and in sensory and perceptual research are proposed as being of value in addition to the measuring of physiological processes.

110

McGehee, C. R., Sabeh, R., and Chiles, W. D., Operator Fatigue and Fighter Range Extension, Wright-Patterson AFB, Ohio, WADC TR 53-380, DDC AD #29,591 (1953).

Abstract:

Research was conducted on certain psychological aspects of 24 hours of confinement in a stationary F–84 cockpit and on the effect of dexedrine upon test performance in such confinement. The 16 subjects were military and civilian volunteers from the Aero Medical Laboratory. They were given a series of four performance tests: (1) a discrimination reaction time test (flipping the appropriate one of four switches, according to the relative positions of a red and green light), performance being measured by reaction time; (2) a dual pursuit task (using stick-controlled and rudder-controlled dials), performance being measured by the total time on target for the two pointers both separately and simultaneously; (3) an addition test (summing rows of digits from left to right, and marking the row when the answer matched the correct number printed to the left of that row), performance being measured by the total number of rows correctly handled; (4) a combination of the first two tests, referred to as the "stress test." Eight subjects comprised Group I and spent two 24-hour periods in the cockpit; the other eight subjects comprised Group II and spent one such period. During the morning of the day of his confinement in the cockpit, each subject practiced the four tasks, until reaching a stable level of performance. A "pretest" was then administered: a 50-minute test cycle of the four tests above, comprising approximately 15 minutes each of tests (1), (2), and (4) and 5 minutes of test (3), with 15-second intervals dividing them. In the afternoon the subject entered the cockpit for his 24-hour confinement. After 10 hours, subjects in Group I were given a pill, either dexedrine or a placebo (a non-medicated sugar pill). One half of Group I received dexedrine the first day they were confined and the placebo the second; the other half were given the pills in the reverse of this order. The subjects in Group II received no pill. From the 10th to the 14th hour, the subject performed the test cycle four consecutive times, with a 10-minute interval between cycles. To compare the confinement period test scores with the pre-test scores, the data were examined in terms of the percent change in performance.

The data revealed a decrement in performance after confinement when compared with the data on pre-confinement performance. The dexedrine, however, mitigated this decrement. Performance under the dexedrine condition was consistently better than that under the other conditions, and, with the exception of the discrimination reaction time test. the dexedrine performance was equal to or better than the pre-test performance. The vehemence of the reports of the subjects indicated that they did not adapt well to such treatment, all subjects being quite verbose in describing the physical discomfort produced by the confinement. It was suggested that the dexedrine's facilitatory affect was that it removed or permitted the individual to ignore his feelings of fatigue, thus, in effect, resulting in an increase in motivation to perform.

This was a well-reported experiment, with statistical analysis of the data supplied in an appendix to the text. However, the experimental design suffers from several defects. First, the tests during the cockpit confinement did not clearly test either performance after 10–14 hours of confinement *or* performance during 4 consecutive hours of testing, since both conditions

were present in the one testing situation. If the authors wanted to test confinement effect alone, the pre-test and the confinement tests should have been of the same duration; then fatigue from testing would not be so easily confused with fatigue from confinement. Second, except for subjective remarks, there was no behavioral investigation of the subjects from the 14th to the 24th hours of confinement. Why have the subjects stay in the cockpit for 24 hours, if no test was to take place after the 14th? Third, there was another complicating variable: Group I underwent two 24-hour confinements, while Group II had only one. Thus, pill-taking was not the only factor which differentiated Group I from Group II, and yet no consideration of this other factor was made in the analysis of results. In addition, the authors omitted reporting the amount of time which elapsed between the two confinements for Group I. However, the authors do mention: "The small number of subjects and the inclusion of a considerable amount of uncontrolled variability in the experimental situation preclude the formulation of any firm conclusions or recommendations."

111

McGrath, S. D., Wittkower, E. D., and Cleghorn, R. A. Some Observations on Aircrew Fatigue in the RCAF-Tokyo Airlift, The Journal of Aviation Medicine **25** (1954).

Abstract:

The purpose of this report was to investigate the question of why some men develop "operational fatigue" while their comrades, even though exposed to the same stresses, do not. Data was gathered through personal interviews, group discussions and questionnaires. The authors admit that the information obtained was purely subjective and had been given in retrospect, and thus is open to criticism. The general conclusions consisted of recommendations for making flight conditions and nonflying time as pleasant as possible, that group discussions could be helpful for making suggestions, and that emotional difficulties or any signs of mental breakdown should be subject to psychiatric advice.

This report serves only to categorize the various areas that should be studied in order to assess the problem. No statistics were provided and many statements were those that were inferred by the authors.

112

Melton, Arthur W., Apparatus Tests, Army Air Forces, Washington, D.C. Aviation Psychology Program Research Reports, Rept. No. 4, AD #651,780 (1947).

Abstract:

This report summarized the uses of apparatus tests in the Aviation Psychology Program for the Army Air Forces and during World War II for selection and classification, routinely or experimentally, of aircraft personnel. Approximately twenty categories of experimental apparatus tests were examined. In each category were introductory, developmental and summary sections with inclusive explanation of the types of tests that were used. The author evaluated the reliability, validity and criterion measures used for each test. Most of the tests reviewed were concerned with manual dexterity; however, there were some categories that apply to the study of fatigue. Among these were: (1) "Stress" Tests and Psychophysiological Tests, including the SAM Muscle-Action Potential Index, Observation Stress Test and Control Confusion Test, Psychogalvanic Response During Serial Choice Reactions, and Psychophysiological Measurements; (2) Visual Discrimination Reaction Tests, including the Discrimination Reaction Test, Visual-Spatial Discrimination Reaction Time Test, Serial Discrimination, and SAM Visual Coincidence Reaction Test; (3) Selection of Radar Operators including a discussion of the psychomotor components, Langley Field Projects and the Carlsbad Army Air Field Project; (4) Psychomotor Performance Under Conditions of Anoxia and Drugs, including a number of experiments using varying amounts of oxygen, effects of sulfodiazine, effects of pressure-breathing equipment at various altitudes, and comparison of a number of psychomotor—pencil-and-paper—tests. The last five sections of the report dealt with special research projects.

This is an extremely thorough report. Excellent methodology is used in developing the various topics and there is extensive statistical analysis to support the author's evaluations of the various tests.

113

Miller, Ralph E., and Mason, John W., Changes in 17-Hydroxycorticosteroid Excretion Related to Increased Muscular Work, in Symposium on Medical Aspects of Stress in the Military Climate, Washington, D.C., Walter Reed Army Institute of Research and the Walter Reed Army Medical Center, pp. 137–153 (1964).

Abstract:

The research reported here is concerned with the question of whether 17–OH–CS levels change when the muscular workload is increased over a period of several days. Two methods of increasing the workload were used:

(1) Six adult male monkeys (Macaca mulatta) in restraining chairs were taught to lift a pail with a rope and pulley to obtain food pellets. The experiment consisted (after a training period of at least three weeks) of two days during which the monkey lifted an empty pail, three days of lifting a pail containing a 5-kg weight, and six days with the empty pail again. Blood was collected through an indwelling cannula in the right jugular, and urine was collected automatically and stored by the day. Although a positive correlation ($r = 0.73$, $p < 0.05$) was indicated between the amount of work done (in kg-m) when the pail was weighted and the 17–OH–CS levels, the authors believe that the rise in hormone excretion was not caused by the increased work, but was an emotional response to the presentation of the weights. This conclusion was based on several items: the correlation between the work done on control days and 17–OH–CS excretion on those days was not significant ($r = -0.26$, $p = 0.05$); The monkey who did the most work on the first day after the pail was weighted did not have the highest hormone excretion values; one animal did a lot of work, but did not have a rise in 17–OH–CS level; and another monkey did not work at all for the three days, yet showed an increase in both plasma and urinary hormones.

(2) Six macaques were also run in a second series of experiments in which the monkeys had to work for their food by climbing—an activity thought to be more natural for them than lifting a pail. Urine was collected, but not blood. Urinary 17–OH–CS levels were measured on a control day, three days of climbing for food, and three more control days. Mean hormone levels rose during the three activity days, but not for every monkey on every day.

The authors concluded that, "although the adrenal glands are undoubtedly important for the performance of work in the rhesus monkey an increased workload, *per se*, imposed over several days, does not necessarily cause a markedly increased excretion of 17–OH–CS in the urine . . . . It is felt that the psychological reaction to the task confronting the animal may be more important than the work itself in causing an increased excretion of 17–OH–CS and that future efforts should be made to separate these two variables experimentally."

114

Minard, D., Work Physiology, Archives of Environmental Health, **8**, 427–436 (1964).

Abstract:

The historical background of industrial physiology and psychology is briefly discussed. with some of the classic studies summarized. The role of the industrial physiologist and physician is characterized as one of assessing the work demands and environmental stresses in terms of resulting strains and deciding whether these are tolerable or excessive. The relatively new field of ergonomics is contrasted with the traditional time/motion approach. Because most laboratory studies on fatigue have used relatively homogenous groups of healthy young adult males, more field investigations in industry, dealing with larger groups which can be stratified by age, sex, work history, and the presence or absence of disease, are urged. Because diseases and disabilities not recognized as occupational in origin constitute by far the largest cause of sickness absence and ineffectiveness of workers, the great challenge now and in the future to occupational health as a professional discipline is to discover and control complex interactions between man and factors in his working environment which lead to increased susceptibility both to acute infectious disease and to the chronic degenerative diseases of aging.

115

Missiuro, W., Kirschner, H. and Kozlowski, S., Electromyographic manifestations of fatigue during work of different intensity, Acta Physiologica Polonica 13, 11-23 (1962).

Abstract:

In order to compare the electromyographic patterns of high- and of low-intensity work carried on till complete fatigue, experiments were made on 15 young men. The subjects lifted on a manual ergograph weights (8 and 2 kg) at a rate of 30 times a minute and constant amplitude of movements. Action potentials were recorded from m. biceps br. and m. triceps br. with contact electrodes during work. EMG-s also were recorded during a single muscular contraction with maximum load. Quantitatively the EMG-s were analyzed by summing the amplitudes of all discharges obtained during particular contraction of the muscle.

Intensive work (8 kg) resulted in complete fatigue after as little as 1.5—3 min whereas in low-intensity work (2 kg) fatigue developed not before 40—140 min. The two kinds of work differed in both the subjective symptoms of fatigue and EMG. In intensive work the integrated electric activity grew consistently and in roughly linear relation to the duration of work. The peak of electric activity was reached at the moment of discontinuation of work; it shows that stimulation of the muscle by volleys of impulses from motoneurons attained maximum. In the final period of work there appeared high potentials of longer duration with a tendency towards periodization, which would seem to suggest synchronization of discharges.

Long monotonous work of low intensity led to different changes in the summary electric activity of the muscle. A characteristic feature was 2—3 waves of rising and falling electric activity of the muscles. Cessation of work, however, occurred invariably at an electric activity lower (by 30—40 percent) than a previous maximum. The high-potential discharges of longer duration, characteristic for fatigue due to intensive work, were never noted, except sporadically and against the background of medium and low amplitude discharges. Ischaemia of the working muscle or increase of the weight lifted a moment before cessation of work increased electric activity of the muscles.

The results suggest that the site of the changes responsible for fatigue is determined by the instensity of muscular work. In great physical effort cessation of work seems to be induced by exhaustion of muscle fibre contractility. This is attended by increased discharges (impulsation) from the motoneurons at an amplitude close to that of action potentials recorded for single muscle contractions. On the other hand, long-drawn work of moderate intensity is discontinued on decreasing discharge of impulses from the nervous contres. This suggests that the changes responsible for cessation of this kind of work take place in the neural element of the motor apparatus. Adequate stimuli from the periphery (e.g., ischaemia) reinvigorate the activity of the nervous centres that supply the muscle, which would seem to indicate greater possibilities of compensation in this type of ("nervous") fatigue. (Author's Summary.)

This is an excellent study, especially for its implications of causes of fatigue in light, long-drawn out work.

116

Müller, E. A., and Reeh, J. J., The Continuous Recording of Pulse Frequency During Occupational Work, Translation by B. E. C. Jenkins. Farnborough, England, Royal Aircraft Establishment, DDC AD #92,150 (1955).

Abstract:

For the continuous recording of pulse frequency over many hours of physical work, a clamp with a photo-cell and lamp has been developed, the total weight of which is 1.2 g. This assembly is attached directly to the earlobe, and makes possible a satisfactory recording of the pulse even in the case of strong movement. The pulse variation causes a voltage fluctuation of about lmV at the photo-cell, and is recorded as a toothed curve on photographic paper by means of a mirror galvanometer and portable recording equipment. For the direct recording of the pulse with a counter, an amplifier has been developed, that, with two steps and a thyratron, produces enough energy to operate a relay. In order to avoid feed-back, the thyratron can be made non-responsive for an adjustable part of the pulse interval after each pulse impulse has been passed through. The amplifier can be worked from the mains, and is independent of the usual mains voltage fluctuations. The construction of the photographic and printing counters for continuous recording over selected intervals is briefly described. (Authors' abstract, modified.)

117

Nagle, Francis J., et al. The Mitigation of Physical Fatigue with "Spartase," Oklahoma City, Federal Aviation Agency, Civil Aeromedical Research Institute, #63-12, DDC AD #429,001 (1963).

Abstracts

Four men (ages 21, 32, 38, and 55) were used as subjects in an experiment designed to investigate the effects of Spartase on work capacity, which was evaluated under normal conditions and at two different stages of induced fatigue: after running for 60 minutes and after running for 40 minutes. This was accomplished by determining the biodynamic potential of each man on a treadmill by means of a Work Capacity Test (WCT). Experimental design consisted of an initial test (WCT I); a 60-minute cross-country run followed by WCT II; and a 40-minute cross-country run followed by WCT III. Of the four subjects, two were in good physical condition and two were in poor condition. Of these latter two, one was subjected to equivalent, but more controlled work-outs on the treadmill in the controlled phase of the study. Pulse rate, blood pressure, pulmonary ventilation, oxygen intake and carbon dioxide output were recorded for all subjects. Tilt table tests were carried out on each subject before the first and following the last WCT in each experimental series. In addition, one-lead ECG tracings from chest electrodes were obtained during tilt and exercise sessions.

After the first phase of controlled study had been completed, Spartase treatment started. Four tablets of 250 mg potassium aspartate and 250 mg magnesium asparate each were taken by one of the subjects (age 55) for one week and by the other subjects for two weeks. The entire testing procedure was then run again.

Results: (a) It was determined by the tilt table test that orthostatic tolerance was affected negatively by physical fatigue. However, the tests showed no significant differences with Spartase therapy. (b) There was no indication of changes in the ECG with Spartase therapy. (c) The performance of the two subjects in good physical condition showed no change with Spartase. However, the other two subjects showed increased performance after Spartase therapy. (d) It was concluded that Spartase was effective in mitigating physical fatigue in untrained individuals engaging in strenuous work, but appeared to have no effect on trained individuals.

This study would have had much greater merit if the authors had used more subjects and had presented statistical analysis of significance. As the value of Spartase has not been completely assessed yet, and as findings on the subject are so diverse, these results cannot be seriously accepted. However, the trend that the authors found indicating that Spartase was beneficial to those in poor physical condition should be further explored and tested.

118

Nagle, F. J., Naughton, J., and Balke, B., Clinical Aviation

Medicine Research: Comparison of Simultaneous Measurements of Intra-Aortic and Auscultatory Blood Pressures with Pressure-Flow Dynamics during Rest and Exercise, Fed. Aviat. Agency, Office of Aviat. Med., AM 66–36, DDC AD #645,496 (1966).

Abstract:

Research was conducted on the comparative accuracy of the traditional "cuff" clinical method of obtaining blood pressure and the laboratory catheterization procedure which measures actual blood pressure. Two healthy men, 40 and 57 years of age, underwent right-sided cardiac catheterization and retrograde supra-aortic catheterization (1) to compare direct intra-aortic blood pressures with those recorded simultaneously by auscultation of the brachial artery; and (2) to study the pattern of pressure and flow dynamics during bicycle work at moderate, strenuous, and maximal intensities. Initially, the subjects performed several control trials on a bicycle ergometer, undergoing all procedures except catheterization. For the experiment, the subjects were anticoagulated with sodium heparin administered intravenously, and chest electrodes were attached for recording a single lead electrocardiogram. Catheters were inserted into an antecubital vein and the brachial artery of the right arm. The arterial catheter was advanced into the ascending aorta and placed approximately 6 cm above the aortic valve. The venous catheter was advanced into the main pulmonary artery. During each minute of a 10-minute period of supine rest, five minutes of sitting, and four levels of exercise, the intra-aorta pressure was recorded and the auscultatory blood pressure was determined from the left arm in the sequence of systolic pressure, 15-second pulse-count and diastolic pressure. Respiratory gas exchange was measured from samples of air collected during the entire 10 minutes of supine rest and five minutes of sitting and the last two minutes of each level of "steady state" work. Inspiratory volumes were recorded from a Tissot spirometer. Blood samples for determination of the arterial and venous oxygen content were taken at the beginning of the final minute of each experimental situation. Cardiac output was calculated by the direct Fick technique. The exercise schedule differed for the two subjects. Subject A began working at 366 mkg/min for a six-minute period, continued pedaling while the intensity was increased to 1525 mkg during the next minute, and maintained this level of work for six minutes. After a five-minute recovery, two additional levels of work were performed continuously, for six minutes each, at intensities of 765 and 1220 mkg respectively. Subject B performed four consecutive six-minute periods of work without a rest interval at levels of 490, 980, 1470, and 980 mkg/min.

Results: (a) In most instances systolic pressures measured by auscultation were in close agreement with the directly recorded measurements. (b) The indirectly measured diastolic pressures were consistently higher than the directly recorded values in one subject, and they were consistently lower than the directly measured diastolic pressures for the other subject. (c) Neither the muffling nor the cessation of sound could be closely identified with minimal intra-aortic pressures. (d) Systolic and mean pressures, minute flow, stroke volume and air oxygen difference increased with greater work intensities. The author recommended that auscultatory *systolic* blood pressure measurements may be valuably used for evaluating cardiovascular responses during exercise tests, but cautioned against the use of *diastolic* measurements obtained by this technique.

The value of this study, with its precise physiological measurements, is unfortunately reduced by the small sample size—two subjects. Such a limited sample practically precludes statistical analysis (which was not attempted) and makes difficult any definitive conclusion about the many variables in the experiment (physiological measures and techniques, exercise patterns, etc.) Adequate control measurements in the exercise experiment were also lacking.

119

Noltie, H. R., A Factor in Postponing the Onset of Fatigue, in W. F. Floyd and A. T. Welford, eds., Symposium on Fatigue, (H. K. Lewis and Company, Chapter 9, pp. 85–91, London, 1953).

Abstract:

The effect of limbering-up exercise upon oxygen debt was studied using a standard exercise of running , miles at 7.5 m.p.h. and a limbering-up exercise of running 0.5 mile at 6 m.p.h. The respiratory exchange in 2 subjects was sampled before, during, and after the standard run, which was made both with and without prior limbering-up.

For both subjects the oxygen debt of the combined run and limbering-up was greater than that for the run alone, but was less than the sum of the two separate debts. The oxygen uptake at the start of the standard run portion was higher if the subject first limbered up, but the steady state values for the rest of the run were not appreciably altered. As the separate oxygen debts were not simply additive, it was concluded that the other benefits of limbering-up could be secured without the handicap of reaching the subject's maximum tolerated oxygen debt (and complete fatigue) as quickly as if they were.

Owing to the small sample size, the infrequency of sampling oxygen exchange, and the resulting simple arithmetical treatment of the results, this study is rated as second class.

120

Pace, Nello, et al., Physiological Studies on Infantrymen in Combat, Johns Hopkins University Operations Research Office, and Office of Naval Research (n. d).

Abstract:

This study examines some physiological changes in men under conditions of extreme stress. It was conducted in a combat situation in Korea, and emphasis was placed on the roles ascribed to the pituitary and adrenal cortical glands in relation to the processes of stress adaptation; and to the reactivity of the autonomic nervous system and the sensitivity of the sensory-cortical mechanism. Twenty-three men in Japan and 18 men in Korea served as control non-combat groups; 34 men were in brief, intensive combat and 13 men in prolonged combat. The pattern of application of the test procedures was essentially one of comparing soldiers immediately after exposure to combat stress with themselves before battle and after a recovery period, and with other troops in non-combat situations. Analyses were performed for a number of blood and urine constituents believed to reflect adrenal cortical activity, ACTH stimulation to determine responsiveness of the adrenal cortex, Mecholyl tests to determine the reactivity of the autonomic nervous system, and sensory cortical tests.

The results indicated that the most significant differences between the combat and control groups were evident in the blood and urine analyses. The intense combat group showed an anticipatory physiological reaction immediately prior to combat; the prolonged group had a longer recovery rate than the intense group. There was no significant difference between control and experimental groups for the ACTH or sensory cortical tests, but the prolonged comhat group had a marked depressed sympathetic response to Mecholyl. Altogether, it is clear that the experience of an intense combat situation of relatively short duration gives rise to an altered physiological pattern which is different from that arising out of a less intensive combat situation of longer duration.

This is a very detailed, comprehensive study, and one which was conducted in the field under conditions of stress not easy to simulate in the laboratory.

121

Patel, A. S. and Grant, D. A., Decrement and recovery effects in a perceptual-motor learning task as a function of effort, distribution of practice, and sex of subject, J. Gen Psychol. **71** (second half), 217–231 (1964).

Abstract:

The effects of three degrees of distribution of practice and four levels of effort were investigated with 120 male and 120 female college students, using the Multiple Serial Discrimeter.

Distribution of practice was measured with zero-second, 30-second, and 60-second intervals between trials. Effort was measured by the force required to depress the response keys, weighted at 200, 400, 600, or 800 g. Prerest learning performance, postrest warm-up, and postrest recovery were analyzed, using the number of errors and the time per trial. On each trial the subject had to make 16 matches of one of four randomly appearing lights with its corresponding response key. A series of 20 prerest training trials was followed by a 10-minute rest interval, after which five more test trials were presented with the lowest effort level and highest distribution level, regardless of prerest condition. Time scores were analyzed with the following findings:

(1) Recovery from decrements accumulating during practice were measured during postrest performance and found to be directly related to the prerest effort and prerest massing of practice. (2) Women showed greater average recovery than men, but an interaction between sex, degree of distribution, and effort complicated the finding. With the greatest distribution of practice, men and women showed equal recovery at the highest level of effort, but women showed less recovery following distributed practice at lower effort levels. This was attributed to differential tolerance of effort by men and women. (3) Warm-up was found to be progressively greater following higher degrees of effort during prerest practice, particularly following the distributed-practice conditions. At other distribution levels, the intermediate (400-gm) effort groups showed the greatest warm-up effect. (4) Warm-up effects were an inverse function of the degree of distribution during prerest practice. (5) Men showed greater warm-up effect following the two lower levels of effort, and women showed greater warm-up effect following the two higher effort levels. It was conjectured that although women had an advantage of acquired sets from other tasks at lower effort levels, the sex differences in physical strength predominated at higher levels of effort. (6) The acquisition curve showed the usual effect of the degree of distribution of practice, with distributed practice leading to superior performance. (7) Although there were no significant simple sex differences in overall prerest and postrest performance, it was found that women were superior in the earlier stages of training, while men became progressively more superior in the later stages of prerest learning and postrest performance. (8) The effort variable had no significant influence in prerest performance, although the highest effort groups tended to be at a disadvantage, and intermediate effort groups were superior in prerest and postrest performances.

This was a good experiment, with methodology, results, and statistical treatment well reported. It is of particular interest for its attention to sex differences, a variable not often considered.

122

Patterson, John L., Jr., et al., Evaluation and Prediction of Physical Witness, Utilizing Modified Apparatus of the Harvard Step Test, Pensacola, Florida, USN School of Aviation Medicine, Bureau of Medicine and Surgery, Project MR005.13–3001, Subtask 1, Report No. 4 (1964).

Abstract:

Several hundred men, ages 18–45, served as subjects in a study designed to evaluate physical fitness. Each man was placed in 1 of 5 categories, ranging from poor to excellent physical fitness, based on his previous athletic training. It was necessary to devise a method which: (1) required minimum skill; (2) used a large portion of the total muscle mass; (3) could assign a work load in proportion to body weight; (4) used simple apparatus. The apparatus used was a 20-inch step of the Harvard Step Test, modified by the addition of a horizontal bar for a handhold. Capacity Step—involving stepping up and down in a 2-second cadence; and Capacity Pack—involving stepping up and down in a 2-second cadence with a load ⅓ of S's body weight—were used as exercises. First, submaximal capacity tests were performed for two minutes. The heart rate during the exercise and the recovery periods were recorded. Then Capacity Step and Capacity Pack Tests were [illegible]. Finally, the tests were run on convalescents.

Results indicated: (1) by using the heart beat in the 3½–4 minute recovery period of the submaximal Capacity Step Test, performance could be predicted in the maximal Capacity Step and Capacity Pack Tests. (2) Endurance and heart rate were correlated to determine physical fitness. (3) The maximum duration of exercise at a prescribed grade of severe muscular work proportional to body weight was the criterion of S's physical fitness. (4) The Capacity Step test could be used with convalescents, as heart rate during exercise decreased with practice. (5) The Capacity Step Test can be most widely used. It was found that individuals who performed it more than 10 minutes were in the good to excellent categories. The Capacity Pack Test could then be applied to rank them. (6) With this method, physical fitness criterion for all age groups could be assigned.

This is a good study, containing the required statistical treatment as well as comprehensive development and discussion of the problem and findings.

123

Payne, Robert B., and Hauty, George T., The Pharmacological Control of Work Output during Prolonged Tasks, Randolph Field, Texas, USAF School of Aviation Medicine, Proj. #21–1601–0004, Rept. #2, DDC AD #16,357 (1953).

Abstract:

This experiment investigated the effects of a motivational technique and an analeptic drug upon performance in a prolonged perceptual-motor task and the relationship between task attitudes and performance. The 80 subjects (volunteer airmen) performed a complicated compensatory pursuit task with simulated aircraft instruments and controls. The task involved an instrument panel of four instruments (the pointers of which were made to drift eccentrically and unrelatedly about their respective nulls) and electronic control devices that could counteract the drifts. The subjects received a preliminary training period (40 trials) in order to establish a substantial level of skill and then continued work for 4 hours (192 trials) under the various combinations of 2 motivational and 5 pharmacological conditions. The motivational treatment consisted of different levels of indoctrination as to the significance of the study for an important operational problem confronting the Air Force. The upper level of this treatment was designed to enhance the subjects' feelings of identification with the problem and with the broad, general purposes of the Air Force. The pharmacological treatment included: (1) Analeptic I (a 5 mg dose of dexedrine); (2) Analeptic II (identified simply as Compound A); (3 Sedative (benadryl-hyoscine); (4) Control (no drug at all); and (5) Placebo (a lactose preparation), to test for any sheer psychological effect that might arise from taking the capsule itself. The treatment effects were appraised in terms of the general course of performance and the terminal levels attained. In computing results, allowance was made for differences in prior ability at the task, as demonstrated in pre-treatment scores. Attitudes and feelings generated in the experimental setting were also explored with 5 multiple-choice questionnaire items, and the attempt was made to relate these subjective reports to both treatment and performance differences.

The results: Very substantial performance differences were produced by the pharmacological treatments, but no appreciable difference resulted between the motivational conditions. The two analeptic drugs prevented the normal loss of task proficiency characteristic of the control and placebo groups, while the sedative hastened this loss. Contrary to general belief, the effect of dexedrine was seen not to accelerate learning or to enhance the display of skill, but to protect the normally progressing learning function against the deterioration of fatigue. The similarity of control and placebo performance gave evidence that there was no effect of pill-taking per se upon performance and that performance effects in this study proceeded from biochemical rather than attitudinal factors.

Both the motivational and pharmacological treatments elicited attitudes consistent with prior expectancy. The greater

motivational condition resulted in more favorable task attitudes than the lesser condition. Likewise, the analeptic drugs induced the most favorable attitudes among the 5 drug groups. However, the task attitudes for the group which took the sedative were not lowered below the levels exhibited by control and placebo groups.

There was no significant relationship between performance and attitudes. This led the authors to conclude that the analeptic drugs achieved their positive effect upon performance by acting directly upon the central processes involved in the task itself rather than through intermediate motivational properties of any euphoria they may have induced.

This was a well-designed and reported experiment, with statistical techniques superior to the ordinary study and with a well-developed introduction and discussion. Dissatisfaction may be expressed, however, with the authors' motivational technique which led to the insignificant relationship between motivation and performance. It is questionable how strong a motivation is "identification with the problem and with the broad general purposes of the Air Force," and perhaps personal rewards of a material or self-enhancing nature would better test motivational influence.

124

Payne, Robert B. and Hauty, George T., The Influence of Drugs, Motivation and Job Design Upon Work Decrement, Randolph AFB, Texas, School of Aviation Medicine, Rept. 55–61, AD #69,413 (1955).

Abstract:

This study was concerned with the effects of analeptic drugs and feedback techniques on the postponement of work decrement and task attitudes. The USAF SAM Multidimensional Pursuit Test was employed as the task. The schedule consisted of a preliminary practice period of 40 one-minute trials separated by 15-second rest periods; 10-minute rest period; 192 one-minute trials separated by 15-second rest periods; and a terminal questionnaire to determine information about task difficulty, task attitudes and other subjective dispositions. One hundred and forty-four volunteer basic airmen, approximately 20 years old, were divided randomly into groups of four and assigned to: (1) one of four pharmacological treatments (no drug; placebo; 5 mg. dextroamphetamine (dexedrine); or 0.5 mg diphenhydramine hydrocholoride with 0.65 mg hyoscine hydrobromide (benadryl-hyoscine)); (2) one of three tuitional treatments (no warning of the fact of deviation, or deviant instrument; warning of signal deviation; or warning of the fact of deviation and deviation instrument); (3) one of three motivational feedback treatments (hazy notion of progress; results of trial just completed; results of entire task progress constantly in view).

Results: (1) Dexedrine was found to postpone or minimize work decrement, while benadryl-hyoscine hastened and enhanced it. (2) An inverse relationship was found between tuitional level and work decrement. (3) A trend was found which indicated an inverse relationship between motivational level and work decrement. (4) Dexedrine generally improved task disposition, while henadryl-hyoscine generally impaired it. (5) Performance effects were found to be independent of subjective effects.

This is a well done study containing good development and discussion of the problems and findings. Thorough statistical treatment of the results is given.

125

Payne, Robert B., and Hauty, George T., Skill Fatigue as a Function of Work-Rest Distribution, Randolph AFB, Texas, School of Aviation Medical Report 57–140, AD #149,040 (1957).

Abstract:

This study was designed to investigate the theory that task improvement varies directly with the length of interpolated rest intervals based on Hull's reaction inhibition theory. The USAF SAM Multidimensional Pursuit Test (CM 813 E) provided a multichannel compensatory tracking task in which the eccentric oscillations of four independent instrument pointers were monitored continuously and kept minimized as far as possible through the operation of simulated aircraft controls. Forty-eight men served as subjects. The experimental design was as follows: (1) A preliminary practice period of 40 one-minute trials separated by 15-second rest periods. (2) A ten-minute rest period during which S was put in one of three work-rest distribution groups—Group A: 192 one-minute trials separated by 15-second rest periods, work-rest ratio being 4:1; Group B: 96 one-minute trials separated by 90-second rest periods, work-rest ratio being 0.67:1; Group C: 48 one-minute trials separated by 240-second rest periods, work-rest ratio being 0.25:1. (3) S was then instructed to begin his task assignment, which lasted four hours.

Results: (1) Decremental rate varied inversely with the length of the intertrial interval. (2) When the amount of work was held constant, the residual inhibition at the conclusion of the reaction sequence was a negative growth function of the length of the intertrial interval. (3) The author implied that interpolated rest periods serve to reduce the work decrement caused by repeated reactions as the rest period affords the inhibition caused by the reaction to subside before the next reaction. However, he makes no statement as to the optimal work-rest ratio, indicating only that further research is needed on the point.

This is a good study which proposes good methodology for assessing work-rest ratios on repetitive tasks. Statistical analysis includes graphic as well as F score representation of the results.

126

Pearson, Richard G., Task Proficiency and Feelings of Fatigue, Randolph AFB, School of Aviation Medicine, Rept. 57–77. AD #140,469 (1957).

Abstract:

This study examined the effect that subjective fatigue has on task performance. One hundred volunteer, experimentally naive, basic airmen were used as subjects. The experimental design was as follows: (1) Ss filled out a 13-item Feeling-Tone Checklist, Form A; (2) Ss practiced 50-minutes on a perceptual-motor task (USAF SAM Multidimensional Pursuit Test); (3) Ss rested for 10-minutes during which they completed Form B of the checklist; (4) Ss performed the task for three hours with feedback every ten minutes; (5) Ss filled out Form A of the checklist. S's performance on each cycle of work (8 trials) was recorded. The results indicated that feelings of fatigue during a three hour task period had no significant relationship with performance level; however, the subjects may have been motivated, not bored, which may have postponed task decrement.

This is a fairly good study. Product-moment correlations were established between performance and change in subjective fatigue ($r = -0.14$), and between performance and checklist scores obtained just before the three-hour performance period ($r = +0.02$). Neither correlation was significantly different from zero.

127

Pearson, Richard G., and Byars, George E., The Development and Validation of a Checklist for Measuring Subjective Fatigue, School of Aviation Medicine, USAF, Randolph AFB, Texas, No. 56–115 (Dec., 1956).

Abstract:

This study consists of essentially four parts: the first part deals with the development of a subjective rating scale of fatigue; the second, a developmental study to estimate item validity and internal consistency of the scale; the third and fourth consisted of validity studies of the scale.

The subjective rating scale was developed by use of the Edwards-Kilpatrick method. The final scale was presented with three response categories available for each item. Item validity and internal consistency was then obtained by subjecting 48 men to fatiguing tasks (using the USAF SAM Multidimensional Pursuit Test) and administering the fatigue scale at

predetermined times. The testing was administered in the morning and afternoon for each man. Results determined item validity for the retained items and indicated that in the A.M. period, the significant items were toward the positive end of the continuum and in the P.M. period, towards the negative end. Equivalent-form checklists were then drawn up and used in the remaining validation tests to provide data for testing unidimensionality, validity and reliability. A group of 100 men was divided into experimental (activity) and control (relaxation) groups and administered the scale at predetermined times. The results of this indicated that the scale met the requirements of unidimensionality. A group of 120 men was divided into three groups and administered drugs—either an analeptic, dexedrine; a depressant, benadryl-hyoscine; or a lactose placebo—and were administered the rating scale to further determine validity. The final scale consisted of a 10-item checklist.

Results indicated that the scale met the validity, reliability and unidimensionality requirements, but further analysis of the test should be done before wide-scale application. Reproductions of the various developments of the checklist are included in the text and appendix.

128

Person, R. S., The electrophysiological study of motor apparatus activity in man, in a state of fatigue, Fiziologicheskii Zhurnal SSSR, **46**, 810–818 (July 1960).

Abstract:

An experimental analysis was made on certain factors causing changes in the electrical activity of a muscle in man, when fatigued. Seventy-five experiments were conducted with 12 men and women, aged 18 to 40 years. Electromyograms were recorded using electrodes placed on the skin, during conditions of static work with a constant load. The data show an alteration in the pattern of work of the nerve centers consisting in the excitation of a greater number of motoneurons and synchonization of their discharges.

129

Pierson, W. R., Fatigue, work decrement, and endurance in a simple repetitive task, British Journal of Medical Psychology **36**, 279–282 (1963).

Abstract:

Twenty-six male 3rd year California medical students (mean age = 28.6 years) were measured for reaction time (RT) and movement time (MT). A chronoscope was activated simultaneously with a neon stimulus lamp. A 150 g microswitch stopped the chronoscope and activated another when the subject initiated the response. A photoelectric beam was placed 11 in from the switch, and its interruption stopped the second chronoscope. RT was read from the first chronoscope and MT from the second. The subject was instructed to respond to the stimulus by releasing the switch and making a forward extension of the hand through the light beam. An audible preparatory signal was presented from 1 to 1.5 sec before the stimulus. The subject was tested repeatedly until he could no longer continue—the limit of endurance. Subjects were asked to indicate when they became bored and when they believed their responses were becoming slower. These data were obtained: (1) "normal" RT and MT (the means of trials 16–20); (2) "fatigued" RT and MT (means of the 5 trials following subject's indication he was slowing down); (3) RT and MT "decrement" (mean of the block of the slowest 5 trials); and (4) "terminal" RT and MT (means of the last 5 trials). Statistics were considered significant at the .05 level. Scores for RT and MT decrement were significantly slower than the others, but there were no differences among any of the other scores. There was a significant relationship for the occurrence of fatigue and RT performance, but not for the MT performance. Seven subjects expressed boredom, and the Kendall rank correlation indicated no significant relationship for boredom and fatigue or endurance. The author concludes that, "For the population represented by the sample and under the conditions of the study,": "(1) The subjective experience of fatigue is not a valid criteria of the ability to perform speed-or endurance-type muscular work.; (2) Fatigue and endurance cannot be measured by work decrement.; (3) Fatigue, endurance, and work decrement are independent variables." This is an excellent, first-class study. See, also, Pierson and Lockhart (1964).

130

Pierson, William R., and Lockhart, Aileene, Fatigue. work decrement, and endurance of women in a simple repetitive task, Aerospace Medicine **35**, 724–725 (Aug. 1964).

Abstract:

15 female college students (mean age of 19.5 years) were instructed to release a microswitch and extend their hand 11 inches through a photoelectric beam upon presentation of a visual stimulus. Reaction time (RT) was measured from the onset of the stimulus until release of the switch, and movement time or speed (MT) from release of the switch until interruption of the photoelectric beam. Each trial lasted 10 sec, and trials were repeated until the subject could no longer continue—the limit of isotonic endurance. Subjects were asked to indicate when they became bored and when they believed their responses were becoming slower. Results were considered significant at the 0.05 level. Endurance averaged 150.7 trials, with an S.D. of 31.5. Analysis of variance indicated no significant differences for MT under normal (means of trials #16–20), fatigue (means of 5 trials after subject's stating that she was slowing down), decrement (means of the slowest block of 5 trials per subject), or terminal conditions (the last 5 trials per subject). Tuky's procedure indicated that the RT "decrement" scores were significantly slower than the other RT scores. The occurrence of fatigue was significantly related to isotonic endurance and to both RT and MT scores under fatigued conditions. Results were compared with scores by males in a previous study (Pierson 1963). The "normal" RT scores of the females were not significantly different from those of the males, but the "normal" MT scores of the females were significantly slower. It is concluded that: (1) men are faster than women in speed of arm movement, but not in reaction time to a visual stimulus; and (2) men can perform a simple repetitive task for a longer period of time than women. but there is no difference in their subjective opinion as to when their performances are becoming slower. Because the sample size of the female subjects is small ($N = 15$) and because the experimental situation is not sufficiently described in this report, this must be regarded as a second class study. Pierson's earlier (1963) study is better, and should be read in conjunction with this one.

131

Platt, Fletcher N., A new method of evaluating the effects of fatigue on driver performance, Human Factors, **6** (4), 351–358 (1964).

Abstract:

A two-man team drove a 1962 Ford Fairlane four-door sedan equiped with a modified Greenshields Drivometer on a 1200 mile trip from Ann Arbor, Michigan, to Philadelphia and return. The test was made on four-lane divided limited-access highways, to permit the monotony of this environment to accelerate fatigue. Data displayed in digital read-out form by the Drivometer, located in the car's glove compartment, included the number of steering reversals made, accelerator reversals, speed changes, brake applications, time, and mileage. As there was no provision for automatic recording of these data, they were written down by one man while the other was driving. Steering reversal rates per minute and speed change rates per minute were also recorded at intervals. Both subjects knew the purpose of the test and also what variables were being recorded. Each driver had about five hours of sleep the night before the eastbound trip, which began about 10 a.m. Sunday and ended at 11:25 p.m. that night. The drivers changed every one and one-half hours, except for the first and last shifts, with half-hour rest stops. The trip west started at 4:30 p.m. Tuesday, with both drivers mentally tired from the day's activ-

ities, and ended at 4:10 a.m. Drivers changed this time only when they felt too tired to drive farther, and rest stops were kept as short as possible, to accelerate tiredness.

Driver Performance Ratings were measured from a set of empirically derived equations involving the average steering reversal rate, average speed, average speed change rate, and average accelerator reversal rate, each over a fifteen-minute period--comparing normal performance with that while fatigued. Neither driver performed as well as his standard during any part of either trip. During the last hour of the first trip, the driver mentioned speed change hallucinations, while the record indicated a constant speed, but showed major changes in steering reversal rates. The westbound trip appeared to be more fatiguing, and both drivers showed subjective signs of fatigue from the start. The one 90-minute period in which data were recorded continuously showed a definite cyclic pattern of the steering wheel reversal rate.

This is a preliminary study for the design of a basic experiment to establish the measurable limits of fatigue and its degrees on a population of drivers. It is a very good attempt to measure performance on a complex task by factoring out those aspects of it which are relevant and quantifiable. The author states that the steering wheel reversal rate appears to be the most sensitive variable to driver, environment. and vehicle characteristics; but he neglects to give an adequate, quantified definition of steering reversal. The indicated cyclic pattern in steering reversal rate may be related to driver attention span, the author suggests. This methodology could also be used to study the effects of drugs, alcohol, and physical deficiencies on driver performance and safety.

132

Plattner, C. M., Heart strain greater in landing on carrier, Aviation Week & Space Technology (March 13, 1967).

Abstract:

This is an article which reports two studies done by Major James A. Roman on pilots on combat missions in Vietnam. He has shown that non-physical stress in pilots was substantially less during bombing than during carrier launching and landing. Both studies employed monitoring of acceleration and electrocardiogram information to ascertain the results. The second study additionally monitored voice and respiration rate. The first study was of visual combat pilots in South Vietnam; the second, of mostly night combat pilots over North Vietnam, where combat was heavier. The combined findings of the two studies were as follows: (1) Heart rates were substantially higher during launching and recovery than during bombing. The pilots confirmed this by identifying the launch and recovery periods as the most demanding parts of the missions. (2) Heart rates were substantially lower on the second mission of the day than on the first. (3) The average heart rate was 87.6 beats/minute, which was lower than anticipated. (4) The results verified findings of previous studies which indicated that risk or danger were negligible factors in determining heart rate in experienced pilots under moderate levels of non-physical stress which was believed to be the type of stress encountered in flying.

Included in this article was a brief discussion of the state-of-the-art of medical monitoring. Some of the findings with this method have indicated that: (1) the heart beat variation in response to non-physical stress was found to be highly predictable within ± three beats; and (2) a very strong correlation existed between heart rate and measured landing error.

The original studies should be consulted before critical evaluation of these results can be made, as they are presented in this article in brief and in a semi-popular fashion.

133

Randall, Walter C., et al., An Analysis of the Desiccating Capsule Technique in the Measurement of Regional Water Losses from the Skin, Wright-Patterson Air Force Base, Ohio, WADC AF TR 6680, Part 14. DDC AD #27,887 (1953).

Abstract:

Various tests of the efficiency and reliability of a means of measuring actual local water loss from the skin are presented here. The device is an aluminum capsule with an aperture area (which is applied to the skin of the subject) of 8.54 cm^2, and a depth of 12 mm. Between 5.0 and 7.0 g of activated alumina is used as a desiccant and placed in the capsule. A thin blotter disc, held in position by a retaining ring 5 to 7 mm from the capsule rim keeps the desiccant in place. When the capsule has been prepared for use, it is covered by an aluminum cover, and may be left for several hours without significant water uptake.

Although the ability of the desiccant to take up water was shown to be a curvilinear function of time, deviations from strict linearity over the range of usage for measuring sweat loss (10 to 20 min) are very small. Application of the capsule to the evaporating surface does not significantly alter the curve of relatively low rates of vaporization. It fails, however, to absorb all the water vaporized at rates above 0.30 to 0.50 $mgm/cm^2/min$. The capsule should not be used for more than 10 min or so when high rates of sweating are expected, and excess moisture must be mopped from the sampled area with a previously tared blotter.

Although the desiccating capsule does not give instantaneous rates of sweating, as does the apparatus described by T. Adams et al. (1963), it is a fairly simple and inexpensive means of obtaining total sweat loss from a small area, and, when several capsules are applied in succession, gross changes in sweating rates during a task can be obtained.

134

Rasch, Philip F., and Wilson, Dodd, Correlation of Selected Laboratory Tests of Physical Fitness with Military Endurance, Military Medicine 129 (3), 256–258 (1964).

Abstract:

This study was made to determine the relationship of the Harvard Step Test, the Harvard Treadmill Test, and the Balke Treadmill Test to the criterion of endurance established by the military, i.e., for males under 40 years of age, the ability to run three miles in utilities with boots and helmet, light marching pack, organic weapon and belt. Fourteen young adult Marines who had just completed a physical conditioning program at Parris Island were used as subjects. The testing was conducted over five days and included: (a) day 1, the Ss ran three miles outside in utilities and boots; (b) day 2, the Ss were divided into three groups and ran three miles outside in marching pack, rifle, helmet and belt, the total weight being 32 lb; (c) days 3, 4, 5, each group performed in the lab, the order of testing being randomized by use of the Latin square design.

Results: (1) The Balke Test was the only test used which showed a marked relationship with the three-mile run with or without the pack. (2) There were extremely low correlations between the three tests, indicating that they measured different aspects of "physical fitness." (3) The correlations between the criterion and the Harvard tests were too low to be of value. (4) The correlation between the Balke Test and running three miles with a pack was high enough to justify use of this test in laboratory situation $r = -0.76$. $p < 0.01$).

This is an average study which utilizes the requisite methodology. Statistical treatment included means, standard deviations, and Pearsonian intercorrelations of the three-mile runs and the test items.

135

Redfearn, J. W. T., Dickens, T. L., and Mitchell, B., The Eosinophil Count as an Indicator of Physical Fatigue, Army Operational Research Group (England) Report, No. 16/57 (1957).

Abstract:

This study examines the effects on the eosinophil count of 3–6 men of a day's march, various durations of exercise, the time characteristic of the count, the effects of marching to exhaustion, and the results of obtaining a mean count for the

group. More than 96% of the total variance was accounted for in this study, with the main sources of variance being listed as: (a) individual variation in general level, i.e., the between-man effect; (b) the eosinophil effect of physical exercise given in the report; (c) the typical diurnal pattern; (d) individual significant day to day variation in the general level; (e) residual variation in these experiments, consisting in part of such third order interactions as the "man-hour-exercise" effect and the "man-hour-day" effect; (f) counting error which accounts for a standard deviation of about 11%.

The statistical treatment of the results includes an analysis of variance on the duration of exercise, the severity of exercise, a comparison of the results with those findings of Acland and Gould (1956), and the detection of differences in the eosinopenic effect. Included also is a fairly comprehensive discussion and recommendations section which projects that the eosinophil count could be a very useful tool in distinguishing the "fatiguing" effects of various types of physical activity (measurable after at least an hour of activity) applicable in both Services and in industry.

This is an excellent study with very comprehensive treatment of the problem.

136

Ricci, B., et al., Comparison of recovery practices following treadmill running exercise, Journal of Sports Medicine and Physical Fitness, **5** (3), 132–135 (1965).

Abstract:

Four male athletic students in their middle and late 20's ran on a treadmill for 3 minutes at a speed of 10 km/h at a 10% grade. On a randomly selected basis, a 10-minute post-exercise recovery was performed either by standing on the treadmill, or by walking on the treadmill at 4 km/h on a level grade. Exhaled air, during recovery, was collected in Douglas bags and analyzed for volume and CO_2 output. Cardiac frequency was recorded continuously using chest electrodes and a Waters cardiotachometer, and rectal temperature was monitored by a probe. Blood pressure was read before exercise and at the end of the recovery period.

Expired air volumes were higher during walk recovery, and the percent of CO_2 in the exhaled air was appreciably higher during stand recovery. Rectal temperature was elevated only slightly during the entire exercise and recovery period, irrespective of recovery method employed. Blood pressure comparisons were remarkably similar and were not affected appreciably by recovery method.

The authors concluded that, in light of the parameters measured, stand recovery appeared to be as effective a recovery method as walk recovery. Unsolicited remarks from the subjects, however, indicated a preference for walk recovery, as they experienced "tired" and "tight" legs while standing. Unfortunately, only a very few subjects participated in this study, and the number of test periods per subject were not mentioned. Only mean and some extreme responses were presented, and no tests for significance.

137

Ruff, S., Brüner, H., and Klein, K. E., Investigations on the Stress Imposed on Aircrew in Civil Jet Aircraft during Long-Range Flights: Report on Results on the North Atlantic Route. Translated by the Technical Information and Library Services, DDC #484,698 (July, 1966).

Abstract:

German crew members on 25 regular airline flights over the North Atlantic were studied to determine stress and fatigue levels resulting from flying jet aircraft. There were 75 subjects in all, divided into four categories: Captain (N=19); Copilot (N=13); Flight engineer (N=21); and Stewardess (N=22). Two types of flights were examined: (1) non-stop flight from Frankfurt to New York with the return flight via Cologne and Munich (flight type I, with 17 examples); and (2) Frankfurt to New York via Cologne and Munich with a non-stop return flight (flight type II, with 58 samples). Physiological and subjective measures were taken for all subjects. A test of circulation regulation (the Schneider test) was taken to determine:

a. pulse and systolic and diastolic blood pressure after five minutes lying down
b. pulse and systolic and diastolic blood pressure two minutes after changing from lying to standing position
c. pulse immediately after climbing up and down a stool (45 cm high) five times in 15 seconds
d. electrocardiogram in standing position
e. oral temperature.

Also measured were:

a. eosinophil count
b. determination of hematocrit value
c. a "hitting test" to test fine hand movement coordination
d. an "eutaxia test" to determine the coarser sensomotor coordination in a state of rest (given alternately on different flights)
e. measurement of optical reaction time.

The subjective measures consisted of two interviews which, in addition to the personal history, requested Yes-No answers about the stresses of the individual flight. There were separate forms for outward and return flights. Physical climatic data were obtained during flight by measuring the temperature and relative humidity with a thermohydrograph (by Lambrecht, Göttingen) in the aircraft. A control group of non-flying personnel underwent the same measures and schedules during two 15 hour periods, from morning to midnight and evening to midday.

The following results were noted:

(1) Mean reaction time increased for the aircrew as compared to the controls for a comparable period. Reaction time for the Frankfurt-New York trip varied 0% from the control group at the start to 120% upon New York arrival. A 24-hour rest did not appear to reduce fatigue, and reaction time was 60% at the start of the return flight and reached 200% by the end of the trip.

(2) Eosinophil count varied greatly for both flight types. Both were lower on all comparisons than the control group. The greatest decrease occurred for both flight types during the 24-hour rest period and then increased to almost the same level as the controls by the end of the flight.

(3) Stress levels during and after transatlantic flights were found to vary in the following increasing manner: direct day flight to New York; indirect day flight to New York; direct night flight from New York; and indirect night flight from New York. The high stress levels did not appear to return to normal after a 24-hour rest period before the return flights.

(4) Activity level—i.e., alertness, reaction time, etc.—was lower for the flight crews than the control group during comparable time periods. The only flight that had a similar activity level to the control was the direct day flight to New York. The lowest activity level for all groups occurred during the night at the "dead point." It was found that the crew on the direct night flight to Frankfurt had the lowest activity level at the dead point, resulting in brief periods of sleep and greatly reduced activity. This fact was of paramount importance, as the stress level for this flight was also extremely high and was felt to be responsible for this dangerous low activity level.

(5) The results of the objective measurements of the psychophysical parameters agreed essentially with the subjective estimates of the subjects when questioned as to their condition.

Evaluation of this report is diffcult for many reasons. It appears to have comprehensive coverage of the topic, but includes insufficient statistics (only percentages and means are cited). The general format is confusing.

138

Ryan. T. A., Muscular Potentials as Indicators of Effort in Visual Tasks, in Floyd and Welford, eds., Symposium on Fatigue, chapt. 11, pp. 109–116, (H. K. Lewis & Co., London, 1953).

Abstract:

A possible physiological measurement of effort was explored: contractions of muscles not directly used in doing a task. By "effort", the author means primarily the subjective experience of the individual as he works. Integrated electrical potentials developed in the muscles were recorded by a four-channel Grass electroencephalograph. The muscular potentials in four bodily regions were studied: the tibialis anterior of the leg, the triceps of one arm. the two ear lobes, and the trapezius at the base of the neck. The subjects were not instructed to avoid movement during the experiment, contrary to such restrictions placed on subjects in previous research. Visual tasks were selected for study because a minimum of movement is necessary in performing them, and the gross movements of the task itself will not complicate the measurement of additional muscular activity. A visual inspection task was developed, in which the subject compared two groups of letters and indicated whether they were the same or different, all groups containing only the letters "c" and "o". The rate of work was controlled by moving the material on a long tape past a small window.

(I). Effect of Glare: 60 subjects, in a single session each, performed the visual inspection task. Each subject worked for three periods of 10 minutes each, separated by rest periods (of a duration not reported by the author). Glare was introduced for one-third of the subjects in the middle period, for another third in the last period, and for the remaining third (the control group) not at all. The glare was produced by a bare, 100-watt bulb, 10° above the working material. and about 30 inches from the eyes. The results were generally in the expected direction in each of the regions studied and in the total of all four regions taken together, where differences were highly significant statistically. However, not all subjects showed an increase in potentials. There was also a very strong effect of the order in which the experimental conditions were presented to the subject: all the significant effects of glare occurred in those subjects who worked under glare during the middle period. Those who worked under glare in the third period produced their highest potentials at this time, but so did the control group, with very little difference between the groups.

(II). Effect of Level of Illumination. Three experiments were conducted on the relationship between level of illumination and muscular potentials: (1) 8 subjects worked for 8 one-hour sessions on successive days, with the illumination alternating between 5 and 18 foot-candles on different days. The results showed higher potentials for 5 foot-candles, but were not statistically significant. (2) 12 subjects worked for six separate one-hour periods, with 5, 15. and 50 foot-candles, each presented twice in varying order. There was no observable relationship between level of illumination and potential. (3) An attempt was made to correct the unavoidable variance in placing the electrodes on different days. The transition from one level of illumination to another was made within a single working session, with the direction of change alternated from day to day. Five foot-candles was compared with 15 in one series, and 2.5 foot-candles was compared with 15 in another. The results showed no significant change in potential levels with changing illumination.

Other studies were discussed by the author to support his conclusions: (1) The level of illumination has very little effect upon the individual once it reaches the level required for discriminating the details of the task. If there are effects upon the visual mechanism or other parts of the bodily system, they must be demonstrated by some method still to be discovered. (2) Muscular potentials can be used on a statistical basis to reflect the relative effort involved in different tasks, even when the subject is permitted relative freedom of posture and movement.

This report was a transcription of a lecture presented to the Ergonomics Research Society. It was a discursive survey of the author's work on the measurement of effort by muscular potentials, and as such was not strictly precise in reporting experimental data. The author's analytic discussion is particularly valuable, relating the consequences of his own research to the experimental work of others and revealing the implications involved so far in this area of research.

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Ryan, T. A., Bitterman, M. E., Cottrell, C. L., Relation of critical fusion frquency to fatigue in reading, Illumination Engineering, **48**, 385–391 (1953).

Abstract:

Subjects were tested while reading at a table set before a large concave hemispherical surround, both painted flat white, and diffusely illuminated by incandescent lamps capable of any brightness level up to 1,000 footlamberts (ft-L). For critical flicker fusion frequency (CFF) determinations, an intermittant light was projected onto a screen set into the surround on the horizontal line of sight and subtending two degrees of the visual angle.

A series of methodological experiments preceeded the fatigue study proper. Since CFF determinations would be made under different intensities of illumination, it was important to select a target light brightness which would be the least affected by surround brightness. Fusion frequencies were therefore determined for target brightnesses of 1,7, and 50 ft-L and for surround brightnesses of 1, 7, 50, and 350 ft-L. A target brightness of 50 ft-L produced the most stable CFF thresholds for the surround brightnesses tested. The effects upon CFF of adaptation by the subject to the general illumination conditions were tested with the target at 11 ft-L and the surround at 0, 2, or 50 ft-L. Adaptation appeared to have no systematic effects upon the CFF level. The effects of the starting rate (base level) of the flickering light and of the rate of increase of flicker upon the CFF level reported by the subject were also investigated. The base levels tested ranged from 18 to 30 cycles per second. and the accelerations ranged from 0.5 cycles/sec/sec to 2.0 cycles/sec/sec. The CFF determination was found to vary directly with both the base level and the acceleration rate.

Three experiments of the effects of prolonged visual work upon CFF were performed: (a) Effects of illumination level during work, with CFF determinations made in the same ambient illumination as the work. Twelve subjects (male and female psychology students) each read *Lorna Doone* for a 3½ hour period every other day for three periods. On each day the subject adapted to the prevailing illumination condition (2, 11, or 50 ft-L) for 15 minutes and practiced CFF judgements, then made 6 CFF determinations. The subject then began reading, and made 6 CFF determinations with a target brightness of 50 ft-L at the end of each half-hour of work. A significant mean decrement in CFF during reading occurred for the 2-ft-L level but not for the others, and some subjects showed an increase in CFF.

(b) Effects of illumination level, with flicker tests under varying conditions of illumination. Each of 32 subjects read for two, 3½-hour periods under two illumination conditions—2 and 50 ft-L. Sets of 10 CFF determinations were made before and after each reading period, with half of the subjects making their determinations at a surround brightness of 2 ft-L and half at 50 ft-L. If a subject was to read at a level of illumination different from that used during the CFF test, the brightness was slowly changed over a 15-minute period to the required level. No significant mean changes occurred for CFF, and there were fewer declines in CFF during reading at the low illumination level than at the higher level.

(c) Effects of glare during reading. Ten subjects each read for two periods. one under the normal conditions described above with the surround illuminated to 11 ft-L, and one period with a 25-watt bulb behind a plate of ground glass (brightest spot was 1100 ft-L) just above the line of vision. CFF increased slightly following reading, both with and without the added glare. The authors concluded that CFF is not a suitable measure of visual strain, and suggested that it reflects rather the general difficulty, stress, alertness, and concentration required by the task.

140

Schane, W. P., and Slinde, Kenneth E., Continuous EKG Recording During Free-Fall Parchuting, Fort Rucker, Ala., U.S. Army Aeromedical Research Unit Report No. 67-7, DDC AD #653,598 (1967).

Abstract:

Heart rate and rhythm of 29 experienced parachutists were recorded on 98 individual jumps, during free-fall and during the periods immediately before and after the jumps. The subjects ranged in age from 17 to 47 years (mean age was 30.4 years), and had a mean of 720 jumps per man. One bisternal lead electrocardiogram of each parachutist was continuously recorded from at least 1 hour before the first exit of the day to at least 1 hour after the last exit of the day on ¼" 0.5 mil Mylar magnetic recording tape by a 3½ lb self-contained recorder. From 1 to 4 jumps were made per subject per day, and most periods of free-fall were 20 seconds long, though 3 were 90 seconds long. A detailed examination on an oscilloscope was conducted for each of the following periods: immediately prior to exit from the plane, free-fall, parachute opening, landing, 5 minutes after landing, any period of unusual rate or rhythm, and all areas noted upon scanning to be other than totally normal.

Mean R-R interval (heart rate in beats per minute = 60/R-R interval) was 0.403 seconds just prior to exit from the plane, 0.363 seconds during free-fall, 0.336 immediately after parachute opening, 0.369 at landing, and 0.465, 5 minutes after landing. Heart rate was at its fastest at parachute opening. Mean duration of tachycardia (accelerated heart rate) per subject was 19.4 minutes prior to exit, and 30.4 minutes after chute opening. Rates above 200 beats per minute were maintained for at least 2 minutes at chute opening by 5 subjects. The R-R intervals for the subjects who made at least 2 jumps on any 1 day were similar for each jump. Correlations suggested that as one accumulates jumps, both the magnitude and duration of tachycardia increase.

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Scherrer, J., and Bourguignon, Changes in the Electromyogram Produced by Fatigue in Man, American Journal of Physical Medicine **38**, 148-158 (Aug. 1959).

Abstract:

36 tests were carried out on 5 subjects of normal physiology. Isometric contractions were studied as well as voluntary weight lifting to the threshold of exhaustion. Integrated, global, and elementary electromyographic (EMG) recordings were made. The integrated sum of the EMG recorded by surface electrodes during the same mechanical performance increases in all work of average or increased power followed beyond a certain time. The global EMG recorded under the same conditions shows an increased amplitude of the potentials and a decrease in their frequency. They tend to assume a sinusoidal appearance. A second class study—cases are few in number, and conclusions are still tentative in part.

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Scherrer, J., Bourguignon, A., and Monod, H., Fatigue in Static Work (La Fatigue dans le Travail Statique), Revue de Pathologie Generale et de Physiologie Clinique, Paris, **60**, No. 716, 357-367 (1960).

Abstract:

Static muscle contraction in man was investigated using 75 male subjects, most from 20 to 22 years old, for 171 trials. Four muscle groups were tested, the medial flexors, the extensors, flexors, and the two quadriceps operating simultaneously. Static loads varying from 3 to 35 kg were held at a constant level by the subject until local muscular exhaustion occurred. Seven trials were conducted with the triceps after arterial occlusion.

Work performed is evaluated in terms of load and time of maintenance of the muscle contraction, the relationship between these factors being expressed as $t = \frac{K}{C^{2.4}}$, where t = time, C = load on the muscle, and K = a constant. The resulting plot of load versus time is hyperbolic for each of the muscles tested.

As compared to work in normal conditions, work performed under arterial occlusion appeared to reveal two causes for local muscle fatigue:

(a) Exhaustion of muscle contractile capacity;

(b) Blocking of circulation, which occurs more severely as load increases above 20 percent of the maximum possible. The authors believe that for light loads the exhaustion threshold is mostly subjectively motivated, and psychic factors are more important than physiologic ones.

There is very little discussion of the work setting or the apparatus employed, and only a very few (7) trials were run with arterial occlusion.

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Schwab, Robert S., Motivation in Measurements of Fatigue, In Floyd and Welford. Chapt. 14, pp. 143-148. Symposium on Fatigue, (London, H. K. Lewis & Co., 1953).

Abstract:

This paper discussed two areas: (1) the definition of fatigue; and (2) the development of a measure sensitive enough to assess fatigue free from motivation. Fatigue was divided into two categories: normal and chronic. Normal fatigue was defined as that which was induced by some kind of activity which dissipated after rest. Factors influencing normal fatigue were: (1) individual differences; (2) variations in the same person from day to day, or under altered circumstances; (3) different incentives or levels of motivation. Chronic fatigue was defined as that which arised from little or no work and which no amount of rest will dissipate. Its cause is due to either structural abnormalities in the neuro-muscular system precipitating premature impairment or to emotional or situational factors causing lowered or absent incentives. The former condition could be corrected by medical or surgical treatment; the latter, by psychotherapy.

Experimentation with recording ergographs of spring and weight types, as well as hanging bar tests, have assessed the strength of the flexor muscles of both wrists. It was determined that the weight type of recording ergograph was superior to the spring type in both reproducibility and ease of manipulation. Tests using the hanging bar demonstrated that different levels of motivation affect performance positively. A portable hand ergograph has also been developed which assesses the subject's hand strength by means of squeezing a rubber bulb which was connected to a recorder.

Attempts have been made to measure muscle strength free from motivational levels in order to compare normal and chronic fatigue subjects. Batrow has produced an electrical stimulator with a high voltage damped wave (45,000 volts) of short duration (7 microseconds). By use of this instrument, human fatigue curves were made of comparisons between normally and chronically fatigued subjects. These curves have been useful in assessing fatigue independent of motivation, the effects of drugs, recovery rates, and muscle intraction.

It was concluded that although various motivational levels give fairly accurate responses to muscle performance under varying conditions, a check on voluntary curves was needed. This fact was more pronounced in chronically fatigued subjects, as motivational levels usually would not affect their performance. Electronic ergography was determined to be a sensitive recorder of human muscular fatigue curves free from motivational levels in normal and pathological situations.

Evaluation of the results of this paper cannot be made without examining the various studies referred to. It is well organized and clearly develops the author's final conclusion concerning the usefulness of the electronic ergography in assessing fatigue.

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Schwab, Robert S., and Brazier, Mary A. B., The Study of Fatigue in Normals and Patients with Neurological and Psychiatric Disorders, Final Report, Cambridge, Mass., Harvard

University, Contract N5–ORI–76/VIII, Report NR 113–141. DDC AD# 205,526, 1958.

Abstract:

This report summarizes ten years of research on fatigue in the following situations: (1) fatigue and impairment in normal subjects, (2) patients with psychiatric symptoms, (3) patients with objective evidence of motor impairment and a complaint of fatigue or tiredness, (4) fatigued patients whose difficulty is due chiefly to medical disease or trouble outside the nervous system, (5) impairment and fatigue syndrome associated with inefficient use of muscles, poor posture, or mechanical and environmental handicaps, and (6) persons with various combinations of the preceeding factors. An unspecified number of "normal" people (medical and college student volunteers, and hospital staff) served as controls throughout the study period. Patients with myasthenia gravis and Parkinson's disease, and institutionalized and private psychiatric patients were used as subjects.

Tests included: (1) a step test using two 12" steps, (2) the hanging bar test, with or without various degrees of motivation provided by the experimenter, (3) hand dynamometers, and (4) electronic ergogram with a Batrow muscle stimulator.

Results: (1) Twenty normal (control) seamen performed 10 to 25 percent better on the 1-minute step test than did 20 psychiatric patients. Lactic acid levels of the normals averaged 4 to 8 mg before exercise and 16 to 30 mg immediately afterwards. Samples 30 minutes after exercise showed a return to normal values. (2) Normals lasted from 40 to 80 seconds on the hanging bar test, with an average of approximately 1 minute, and produced lactic acid levels nearly identical to those of the step test. Psychiatric patients averaged around 40 to 50 seconds, and the average myasthenia patient would fall off in 30 to 40 seconds. The psychiatric patients produced slightly higher lactic acid values than those of the controls, when corrected for the duration of hanging, while the myasthenics had much lower levels. Electromyograms were nearly the same for the controls and psychiatric patients, and did not change significantly during the hanging. (3) Injection of neostigmine produced a nonsignificant decrement in hanging-bar performance for normals and psychiatric patients, but led to a marked increase in both motor performance and lactic acid level in myasthenics. (4) In normals, patients with psychiatric complaints of fatigue, and myasthenics, the voluntary power available to a muscle group pulling a weight was found to be two to six times greater than the effect produced by electronic stimulation of a group of motor points in one muscle. In patients with hysterical weakness or with akinesia, however, the ratio was often reversed. (5) Changes in motivational level did not generally have much significant effect on performance of the finger erograph, except for Parkinson patients with symptoms of akinesia.

A number of brief case histories are presented, as well as methods for diagnosis and therapy for complaints of tiredness and fatigue.

This report contains neither raw data nor tabulations—discussion is in terms of impressions of approximations to averages or ranges. Such results that are presented are extremely limited in detail and are in such form as to make comparisons between patients and controls very difficult. The number, ages, and sex of subjects and controls are generally not given.

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Shands, H. C., and Finesinger, J. E., Psychiatric Aspects of Fatigue, Harvard University Medical School, Dept. of Psychiatry, and Mass. Gen. Hospital, Dept. of Psychiatry, Boston, Mass. (ONR Contract N5 ori 76, Proj. XIV 05664, Tech. Rept. 12, DDC ATI 210, 579, (1949).

Abstract:

The circumstances and feelings accompanying the onset and variations in fatigue states in a series of 100 psychiatric patients (57 males and 43 females) who complained of chronic fatigue in the absence of previous exertion or medical disease. The patients were interviewed from six to more than thirty times each, using a method to try to stimulate relatively free association to specific topics and goals. In addition, a questionnaire was administered to 35 patients but this was abandoned after statistical examination indicated that no new information was being elicited by the questionnaire. The 100 patients discussed were those for whom data were the most adequate of 150 patients seen in the context of this particular investigation. Although the income levels varied widely among the group of patients, most were in precarious economic adjustment. Family histories, sibling patterns, childhood neurotic traits, and so on, were not investigated in an adequately detailed manner.

Although the authors had anticipated that a definite group of patients would turn out to have chronic fatigue without any other symptoms, this was in no case found to be true—in all of these patients it was possible to make a diagnosis of some type of psychoneurosis, most prominently (62%) a neurosis associated with anxiety symptoms. Hysteria was the primary diagnosis in 19 patients and reactive depression in nine, although the authors point out that depressive symptoms were present "almost invariably to some degree." The situations in which the symptoms were precipitated were determined for 50 patients, and the list includes the usual difficult situations in any life—love affair (11 patients), marriage (10), surgical operation (9), job demotion (7), and loss by death or separation (7), et cetera. The emotions found most prominently were anxiety, depression, feelings of rejection, and guilt.

A long series of brief case histories is provided to illustrate the various symptoms, varieties of acute psychosomatic fatigue, and situations contributing to rapid alterations in chronic fatigue states. Psychoneurotic fatigue was seen not to be a disease of the "intelligentsia," but primarily a disease of those individuals whose major preoccupations are anticipatory: they foresee and react to too much of what may be unpleasant in the task. Fatigue is proposed by the authors as a feeling which signifies a need to desist from dangerous or potentially dangerous behavior. The data are perceived as supporting the hypothesis that a feeling of fatigue can be explained more satisfactorily as the conscious manifestation of a defensive inhibition of overt aggressive activity, rather than as the result of energy consumption in the past.

146

Shannon, Ira L., Parotid Fluid Steroid and Electrolyte Responses to Exercise, Brooks Air Force Base, Texas, USAF School of Aerospace Medicine, SAM–TR–66–31. DDC AD #632,501 (1966).

Abstract:

This study investigates the effects of exercise on body weight, pulse rate, parotid flow rate, and the levels of free 17-OHCS, sodium, potassium, and chloride in parotid fluid. Subjects were six males between the ages of 17 and 22 years, in a military situation. One hour after breakfast, the subjects were weighed, pulse rates were taken, and a control parotid-fluid specimen was collected. Fruit-flavored, extrasour candy drops were used to elicit flow, and a five-minute accommodation sample was collected and discarded before test collection. At least 8 ml of saliva was collected in graduated tubes. Subjects then went on a two-hour, ten-mile hike over a level course. Immediately afterwards, the subjects were weighed and a second parotid-fluid sample was obtained. Following two hours of rest, a third sample was taken. This procedure was followed on five successive days. Four chemical constituents of parotid fluid were analyzed, for both their concentration and secretion rate: free 17-OHCS, sodium, potassium, and chloride.

The five days of exercise brought about a significant ($p < 0.01$) decrease in mean body weight, from 173.4 lb to 170.7 lb. The mean preexercise pulse, 79.2 bpm, was significantly lower than the mean of 104.4 after 2.5 miles of hiking. Pulse rates after 5, 7.5, and 10 miles were 109.8, 109.7, and 113.8—none of these significantly different from the rate at 2.5 miles. The pre-exercise parotid-fluid flow rate of 2.12 ml/min. was not significantly different from the means of 2.06 and 2.19 at the post-exercise periods. No significant differences were found between any of the mean pre- and post-exercise concentrations or secretion rates of any of the four parotid-fluid constituents

measured. A significant ($p < 0.025$) day effect was found in the chloride (mEq /liter) data. Significant ($p < 0.01$) interactions between days and times within a day were found for flow rate, sodium (mEq/l), sodium (mg/min), body weight, and pulse rate—indicating that the time trends were not the same for all five days.

The effects of the very small sample size (six subjects) used in this experiment are difficult to determine, as neither ranges nor standard deviations are presented for any of the measures. Three of the five graphs give at first glance a misleading impression of the actual differences found before and after exercise, as their ordinates are not zeroed. No mention is made of the apparatus used to collect parotid fluid, nor of how the rate of whole fluid flow was determined. Parotid-fluid analysis promises to be useful in assessing human effort, but, considering the deficiencies of this experiment and its contradiction of previous work, the results presented here should not be accepted without verification.

147

Shannon, Ira L., Effect of Mental Exercise on Parotid Flow Rate in the Human, Brooks Air Force Base, Texas. USAF School of Aerospace Medicine, SAM–TR–67–36. DDC AD 654,293 (1967).

Abstract:

Investigators have previously reported that mental exercise increases salivary output, that it decreases output, and that either an increase or decrease may be found depending on the normal flow rate pattern of the subject. Three experiments are reported here, all using systemically healthy males, ages 17 to 22, and members of a barracks-dwelling military enlistee population. Sampling began at 7:30 a.m., with subjects in a fasting state. Mental exercise consisted of adding columns of whole numbers four digits wide and four digits in height. A small metal collection device was positioned over the orfice of the right Stensen's duct to collect parotid fluid.

In the first experiment, fluid was collected under as nearly unstimulated conditions as possible, over two 45-minute periods. Thirty-five control subjects sat quietly for these two periods, a second group of 35 performed the mental exercise during the second period, and a third group of 35 worked the problems during the first period. Chewing paraffin was used as an exogenous stimulant in the second experiment. After a 10-minute acquaintance interval, each subject provided two 30-minute samples, with the participants grouped as in the first experiment. The third experiment was identical to the second, except that the eliciting agent was a stick of sugared chewing gum, renewed at 5-minute intervals.

Analyses of variance revealed no significant effects of the mental exercise on parotid flow rate for any of the experiments. In the paraffin-stimulation experiment, there was an indication of a decrease in flow rate from the first to the second period. regardless of experimental condition.

Although this is a very good study, the author does not detail the results of his test for significance, nor does he state what his level of significance was. Records were kept of the number of problems worked by each subject and the number of right and wrong answers, but correlations between flow rate and degree of arithmetic accomplishment were evidently not run.

148

Sharkey, B. J., McDonald, J. F., & Corbridge, Lynn G., Pulse rate and pulmonary ventilation as predictors of human energy cost, Ergonomics **9** (3), 223–227 (1966).

Abstract:

This study compared the precision of prediction of human energy cost afforded by the pulse and ventilation rates. Four males (ages 21–25) went through an orientation and training phase. Each S filled out a checklist relative to sleep, exercise, needs, recorded oral temperature and body weight; and was then fitted with a breathing collection apparatus (Douglas bag), electrodes, and radiocardiograph transmitter. Expired air was obtained in the last two minutes of a seven minute exercise period and was then collected over mercury in a Bailey bottle for duplicate analysis in the Scholander apparatus. The volume of air in the bag was measured in a chain-compensated gasometer and reduced to STPD.

The experimental design consisted of the following: (1) S performed six treadmill tests. The treadmill was operated at a speed of 3.5 mph, and S was instructed to walk on it with grades of 0, 4, 6, 8, 10, and 12%—the order of grade being randomized. (2) Pulse rate, ventilation rate, and energy cost measures were recorded for each test and used in the derivation of individual regression equations for the pulse rate and oxygen consumption relationship and the ventilation rate and oxygen consumption relationship. (3) Predictions were made for O_2 consumption for three tasks: (a) treadmill walking (3.5 mph, 2% grade) while carrying a 23 lb weight in a static constriction (held in hands, arm flexed at 90°); (b) cycling a bicycle ergometer (6200 ft lb per min); (c) hand-cranking the bicycle ergometer (2000 ft lb per min).

Results: (1) Analysis of variance for the differences in percentage error of prediction based on pulse rate measures did not reveal significance. ($F = 3.22$): (2) Analysis of the ventilation rate predictive errors resulted in significance ($F = 4.10$), with the difference between hand-cranking and the 6% walk and between treadmill walking with the static constriction and the 6% walk. (3) It was concluded that: (a) greater accuracy was obtained using the ventilation ratio as predictor; and (b) greater precision resulted when the work task corresponded to the activity used to derive the predictive equation, i.e., the use of a predictive equation based on work done with the legs was least useful when applied to other muscle groups, in this study with the arms.

This is a good study, although more subjects should have been used to reduce individual differences. The discussion section contains suggestions by the authors for further research.

149

Shaw, Daniel L., Chesney, M. A., Tullis, I. F., and Agersborg, H.P.K., Management of fatigue: a physiologic approach, American Journal of Medical Science **243**, 758–769 (1962).

Abstract:

Subjective effects of potassium and magnesium salts of aspartic acid were evaluated for 163 subjects, including fatigued patients and normal and placebo controls, at the University of Tennessee School of Medicine. The active medication and a placebo were administered to some of the subjects in separate blind studies, double blind cross over trials were conducted with others, and a group of normal volunteers received the aspartates. In each trial, the majority of the fatigued patients reported a positive response: "feeling better" when they had been given the active drug, and only a few gave a positive response with the placebo. Of 46 normal, nonfatigued volunteers who were given the drug with no advance information except that it was safe, 4 reported a positive response.

Further studies were made with 31 patients to correlate the subjective results with an objective measure—an electronic rheotome. Eight patients reporting chronic fatigue were compared with 11 normal volunteers. The difference between the two groups was insignificant for the slope of the peroneus brevis muscle response curve and significant at the 0.01 level for the slope of the common peroneal nerve. The fatigued group was given aspartates and the slope of the muscle curve increased ($p < 0.05$), but the nerve curve remained unchanged. The relationship between these objective results and the patients' subjective reports was stated to be 88%. Rheotome studies were performed on 12 additional patients suffering from debilitating diseases. Nine of these patients complained of fatigue, and when their rheotom curves were compared with those for normal subjects, it was found that muscle was hypoexcitable (fatigued; $p < 0.01$) and nerve moderately so ($p < 0.20$). When these patients were treated with spartates, the intercept of the nerve rheotome curve decreased significantly ($p < 0.05$), but neither its slope nor the slope or intercept of the muscle curve changed significantly ($p < 0.20$, 0.40, and 0.45, respectively).

150

Shepherd, R. D., and Walker. J. Absence and the physical conditions of work, British Journal of Industrial Medicine, **14**, 266–274 (1957).

Abstract:

Employee records were examined in an engineering firm and two iron and steel works, and age, length of service, wage, job description, and absence record for one year were recorded. Job conditions were assessed by managers and foremen according to physical heaviness, continuity of working, temperature, dust, and fumes. An absence was defined as an occasion in which a worker missed one or more consecutive shifts when he was supposed to be on the job. Used as indices of absence were the percentage of shifts lost and the number of absences expressed as a percentage of the number of possible shifts.

Results: (1) Absence was lowest among the men in the 35 to 44 year age group, and was greater in both the younger and older groups. The increase among the older men was more marked for the lost time rates than for incidence rates. No tests were run for the significance of these, or most of the following, results, however. (2) There was a small and irregular decrease in absence rates with jobs requiring increasing exposure to heat. (3) There appeared to be no consistent relationship between absence and whether work was continuous or had some or many pauses, although in the over 45 age group, there was an association with shifts lost—men on continuous work having more absence. (4) The presence of dust or fumes did not appear to have a consistent effect on absences. (5) There was an increase in both the amount and incidence of absence with an increase in heaviness of work on a three-point classification. (6) When work was continuous or had some pauses in activity, absence rates decreased as the work also became lighter physically. On heavy work, absence decreased as work pauses increased. Thirty percent of the men on heavy work and only 13 percent of those on light work had more than 6 absences in the year; conversely, 47 percent of the men on heavy work and 64 percent of the men on light work had 0 to 3 absences.

It is unfortunate that, because of the multiplicity (296) of jobs studied, no objective measurements of working conditions were made. Except for the heaviness of work. no analyses of significance were conducted, with trends in the results being accepted on their face value. This study is better than many management studies, but seriously lacks the quantification of such work as that done by Brouha.

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Simons, David G., Prather, Wesley, and Coombs. Franklin K., The Personalized Telemetry Medical Monitoring and Performance Data-Gathering System for the 1962 SAM-MATS Fatigue Study, Brooks Air Force Base, Texas, USAF School of Aerospace Medicine, SAM–TR–65–17, DDC AD #467,733 (1965).

Abstract:

This report describes the instrumentation used for gathering and recording data for the 1962 U.S. Air Force School of Aviation Medicine-Military Air Transport System Fatigue Study at Dover Air Force Base, Delaware. A 6-channel personalized biomedical radio telemetry systeem was used to transmit and record electroencephalograph, electrocardiogram, respiration, skin temperature, basal skin resistance, and galvanic skin response. Three pilot-control functions and 3 aircraft instrument readings were continuously recorded. The total biomedical system included sensors, transmitters, and batteries worn in a vest adjustable through lacings to fit a wide range of people, and the receiver-discriminator rack. One channel was used for monitoring voice communications, and time signals were received from the National Bureau of Standards Radio Station WWV. Data were recorded on a 14-channel, precision. portable, 1-inch magnetic tape recorder operated at 1 7/8-inches per second. The recorded biomedical measures were found to be generally satisfactory for analysis intended for visual interpretation of patterns and trends, but they required extensive preprocessing and editing to be used for computer quantification of patterns. Subcarrier drift of some of the radio channels was a serious problem.

152

Singleton, W. T., Deterioration of Performance on a Short-Term Perceptual-Motor Task. In Floyd and Welford, Symposium on Fatigue, Chapter 17, pp. 163–172 (H. K. Lewis & Co., London, 1953).

Abstract:

In this experiment, it was shown that in a perceptual-motor skill a kind of fatigue developed in a short time which appeared to be central in origin. The measure of performance was the time between movements. Fatigue was defined as a change in the rate of performance.

S sat with a control lever between his knees and faced a display consisting of a red cross on a dull black vertical surface. Each point of the cross contained a neon light, outside of which a filament lamp was placed which could light an arrow pointing away from the center of the cross. S was instructed to push or pull the lever in front of him under one of three conditions: (1) Direct task: top arrow illuminated, move the lever in the direction which corresponds directly with the position of the red light. (2) 180 task: bottom arrow illuminated, move the lever in the direction opposite to that indicated by red light. (3) 270 task: left arrow illuminated, move lever in the next direction clockwise from the red light. The red light went out when S made the correct response. The next task appeared when S returned the lever to the center of the control. After 64 correct responses, the trial ended. Thirty subjects were divided into three groups containing five naval ratings and five students and assigned to one of the three conditions. Each group was instructed in one of three ways: (a) the light that illuminates the arrow stays on all the time, ignore it; (b) there are four small red lights which are controlled by the lever; only one light stays on at a time; or (c) the lever moves in four directions corresponding to a red cross. All were told that by moving the lever the light would be put out, but were not instructed in what direction to move the lever. S was instructed to put out the light as quickly as possible. After six practice trials, the experiment began. The task time varied from 20 seconds to two minutes. with the average being about 30 seconds. The duration of the trial was controlled by the rate of correct responses S made. The experiment consisted of six trials.

Results: (1) The first half of the trial (32 correct responses) was shorter than the second half for all but the first trial. This effect increased with task difficulty—which was rated Direct–180–270—from low to high. (2) The center time (interval between the appearance of a stimulus and the initiation of the correct response to it) and the rate of deterioration increased linearly with task difficulty and throughout the trial. (3) There was no significant change in the movement time (interval between the entry into a channel and the return to center). (4) When S received a stimulus which was the same as the previous one, he took longer to initiate a response to it in the Direct task condition.

This was a well-executed study, containing a good discussion section. Statistical analysis was carried out at the 0.05 level of significance for several analyses of variance.

153

Smith, H. P. Ruffell. An Investigation of Pilots' Work Load and Working Conditions in a Civil Air Line. Air Ministry (England), FPRC/1190, DDC AD 484 517L (1961).

Abstract:

The pilot's work in one air ilne was investigated by a team of four researchers during August to October 1961. Members of the team flew with the pilots, individual observers being rostered with particular Captains for a duty period of usually five to six days. They served essentially the same duty hours and were subject to the same traveling and domestic stress. There was a massive recording of data in many areas, among them sleeping hours, meals, smoking, emotional states, errors, cockpit atmosphere (pressurization, temperature, hu-

midity, glare, noise, vibration, lighting), meteorological conditions, instrumentation, air speed, air traffic control, communications, and navigation.

The authors admitted the absence of an adequate measurement of fatigue. Work decrement in this case was not a good indicator, because there were generally too few flight mistakes to allow any significant correlations. Yet it was observed that some errors, for example in instrument setting and reading, occurred especially at the end of an arduous day of work. No steps were taken in this study to use more subtle measurements of pilot misjudgement (Cf. K. F. Jackson, 1956) that might provide more workable data.

Though no evidence of gross skill-fatigue was found, physiological and psychological stresses known to have deleterious effects on mental and physical skills were observed. The main fatigue-producing factors were thought to be disturbances of sleep rhythm, high temperatures, extremes of humidity, communication and navigation loads. It was suggested that the environmental and operating load should be considered in evaluating aircrew work, rather than flying time and duty hours alone. A scoring system was proposed by which different aspects of the work load might be assigned points, and a reasonable work load was estimated at 18 points per day according to this scale. Many specific suggestions were offered of ways to improve work conditions, pertaining, for example, to work shifts, instrumentation, and information channels.

This study is in the nature of a general investigation and is in no way a controlled scientific experiment. The conclusions were generalized from a mass of detailed observations and are not statistically analyzed. Some of the variables were precisely measured (like temperature and air speed), but most (like fatigue and stress) were only generally observed. This study has more practical value for airlines interested in suggestions for equipment, environment, and work shift changes than for scientists concerned with experimentally confirmed relationships.

154

Spaulding, W. B., "The Clinical Analysis of Fatigue," Applied Therapeutics, **6**, 911–915 (1964).

Abstract:

A group of 4,000 consecutive medical out-patients at a clinic in Toronto, Canada, is analyzed as to their most common presenting symptoms. Fatigue was the chief complaint in 280 patients (7% of the 4,000). ranking fifth in prevalence. Fatigue is defined by physicians differently than by physiologists, and may be considered by patients as "a feeling of difficulty in doing things." 51% of the 4,000 patients were men, but 63% of the 280 "fatigued" patients were women. The average age of the whole group was 40 years, and those over 40 had twice the frequency of physical disorders. 50% of the causes of fatigue were psychiatric disorders, usually (68%) an anxiety state, less commonly (13%) a depression. Endocrine, cardiovascular, respiratory, and hematological diseases each contributed 7 to 9% of the causes. An orderly approach to the symptom should include a description of the character, duration, circumstances of onset, time of daily maximal intensity, precipitating and relieving factors (especially upsetting cirumstances, and accompanying symptoms). Almost all the major systems of the body had representations in the list of physical causes of fatigue. The older patient, of either sex, was more likely to remain undiagnosed as to the cause of fatigue than was the younger patient. The use of even such simple quantified techniques as percentages is admirable and is regrettably not often found in this type of article (see, for example, D. L. Wilbur, 1953). This report is an excellent one for its type.

155

Strydom. N. B., and Wyndham, C. H., Natural state of heat acclimatization of different ethnic groups (with Discussion by Baker and Harrison), Federation Proceedings **22** (3), 801–809 (1963).

Abstract:

This is a preliminary report of rectal temperature, heart rate, and sweat rate responses to a standard heat and humidity stress by 168 males from different populations. Samples ranging in size from 7 to 33 individuals were taken of 11 different groups: French soldiers and Chaamba Arabs in the Sahara Desert, River Bushmen (measured in both winter and summer), Kalahari Desert Bushmen, Australian Aborigines, White Australians, Bantu, White South Africans, Acclimatized Bantu, and Acclimatized White South Africans. A standard heat load of 90° F. wet bulb and 93° F. dry bulb, wind velocity of 50–80 feet per minute, and a work rate of 1.0 liters oxygen intake per minute was maintained in a portable climatic tent. The work consisted of stepping on and off a step at a metronome-controlled rate of 12 steps a minute for 4 hours, or less if a rectal temperature of 104° F. was reached before then. Height of the step was varied according to the subject's body weight to attain a constant work load of about 1,560 foot-pounds per minute. Observations on body weight, pulse rate, and rectal temperature were made at rest at the end of each hour during the experiment. Drinking water was supplied freely, and sweat rates were calculated from body weight differences corrected for water drunk and urine passed.

Results: (a) *Rectal temperature.* The white South Africans had by far the worst response of the 3 Caucasian groups, with only half of them enduring for 4 hours, and with a mean temperature at the end of 103.7° F. Acclimatized South Africans and acclimatized Bantu had the lowest mean rectal temperatures during and at the end of the exercise, with 101.0° F. and 100.7° F., respectively at the end of the fourth hour. The Arab, Aborigine, Bantu, and 2 Bushmen groups reacted very similarly to each other. There was no significant difference between the summer and winter responses of River Bushmen. (b) *Pulse rate.* Mean rates at the end of the fourth hour ranged from 122.3 beats per minute for acclimatized Bantu to 173.6 for the white South Africans who lasted that long. The Bushmen and Bantu showed a distinct leveling off after 2 hours of work, and none of the acclimatized Bantu exceeded 150 pulse beats per minute. River Bushmen pulse rates were all higher in the summer than in the winter. (c) *Sweat rate.* Sweat rates of unacclimatized subjects decreased with time to such an extent that their skins appeared dry but were actually still clammy to the touch. River Bushmen had higher rates in summer than in winter. Arabs and Kalahari Bushmen (both living in desert conditions) had significantly higher sweat rates than natives of tropical and temperate regions.

The authors conclude: "It seems that there is but little difference between ethnic groups in heat tolerance provided that they have been similarly active in the same environmental conditions. There is, however, a big difference in the manner in which various groups respond to heat with regard to pulse and sweat rates."

There are a few problems with this study, which were mentioned by the discussants: (1) Sample size was very small, and sample selection procedures were not described; (2) it is questionable whether results obtained under hot-wet conditions can be generalized to other heat and humidity conditions; (3) Samples should perhaps have been matched or controlled for body composition.

156

Swanson, J. N., Bauer, W., & Ropes, M., Evaluation of eosinophil counts, The Lancet **262** (1), 129–132 (1952).

Abstract:

The diurnal variation of eosinophil cells was examined in order to determine the optimal schedule for detecting eosinopenia. Five healthy persons (three men and two women: aged 21–49), five patients (two men and three women, aged 16–51, with active rheumatoid arthritis), and three men (aged 21–42, with rheumatoid spondylitis) were used as subjects. Hourly eosinophil counts were taken for each S from 8:00 A.M. to 6:00 P.M. Capillary blood was used, and the count was determined by the phloxine-in-propylene-glycol method. Adrenaline and A.C.T.H. tests were also done.

Conclusions: (1) A diurnal variation was found in all cases: a high rise in morning count, a falling-off until about midday; a slight rise thereafter, with a fall again in the early

afternoon; finally, a rise towards evening. (2) The patients showed greater diurnal variation than the healthy subjects. (3) Counts must be done at the same time each day if comparisons are to be made of solitary eosinophil counts. (4) The morning is an unsuitable time for measuring induced falls. (5) The maximum eosinopenia during the adrenaline test can occur before the fourth hour. It was recommended that counts be done at the second and third hours if counts at 0 and 4 hours indicate a partial response. (6) The effect of normal needs on the eosinophil count was disregarded for the purposes of evaluating moderate or large eosinopenias.

This study is deficient in many aspects. There is not sufficient detail in developing the report, making it difficult to determine exactly what the authors did (e.g., there is no clear statement as to the schedule of taking blood samples, nor which method they used to determine the count). There is not sufficient statistical treatment to warrant acceptance of the conclusions. It appears to be a good study, but stricter analysis of the entire procedure and results is needed.

157

Taylor, B. B., The fatigued worker, Western Medicine **2**, 535–538 (1961).

Abstract:

Ninety-two normal adult members of a health service plan complained of persistent fatigue unrelieved by rest, which was beginning to interfere with their work. They were treated with the potassium and magnesium salts of aspartic acid and with placebos, under double-blind conditions, by a physician who knew them well. Their appearance and behavior were closely scrutinized, and the information they gave at each clinic visit was carefully analyzed by the examiner. Each patient received 2 weeks' supply of unidentified tablets, distributed at random. with instructions to return in 3 weeks, but no explanation as to what benefit might be expected. At the second visit an additional 2 weeks' supply was provided. Some received medication for a total course of 6 weeks. When the code was broken it was found that 36 patients had received the active agent only, 38 had received the placebo only, 11 had received first the active substance, then the placebo, and 7 had received the placebo then the active medication. The response was positive in 80 per cent of the trials with the potassium and magnesium salts of aspartic acid. and questionable to positive in 9 per cent with the placebo (the medication had been crossed over in 18 cases). Examination of the records for the 20 per cent for whom the active medication failed showed that these patients were suffering from psychic factors, such as severe anxiety and depression. The physician who knows the life patterns of his patients should be able to select, on this basis, those whose tiredness may be expected to respond to therapy with the magnesium salts of aspartic acid. This is a good study, even though patients' responses cannot be quantified in this type of experiment.

158

Tebrock, H. E., et al., A combined psychic and somatic stimulant in the management of industrial fatigue and mild depression, Internat'l Record of Medicine, **172**, 696–701 (1959).

Abstract:

Research was conducted with a new stimulant formulation of 3 analeptic drugs (*d*-amphetamine sulfate, pentylenetetrazol, and niacin), combining smaller amounts than ordinary of each, in an attempt to reduce side effects without interfering with the desired stimulant action. The preparation was administered for periods ranging from 1 to 12 weeks (average 4–5 weeks), in capsules taken 2 to 3 times daily by 63 patients. The patients comprised 2 groups: (1) 42 middle-aged patients (average age of 46 years) suffering from fatigue and depression apparently of a psychosomatic nature; and (2) 21 elderly, senile patients (average age of 67 years), most of whom suffered from arteriosclerosis or hypertension, with complaints also of memory lapses, fatigue and depression. The patients were seen both in a geographically far-flung industrial practice (including retired workers) and in medical office practice.

The results: 76% of all patients derived benefit from the medication (86% of the older and 71% of the younger group). Excellent results were obtained in the elderly group, with marked improvement in powers of concentration, increased working efficiency, and less complaints of fatigue and depression. The drug did not, however, appear as useful in the younger group, in whom side reactions appeared frequently enough to detract from the beneficial effects that were obtained. The most common side effects (which occurred in 33 of 63 patients) were flushing, insomnia, anxiety, and nausea—some of which cleared up on reducing dosage, or disappeared with continued administration. In the younger patients, however, the side effects were such as to warrant discontinuance in 26 cases. It was concluded that stimulant drugs, such as the one under study, if occasionally used when needed in working situations, might improve the production records of older persons.

This was merely a fair clinical study, with variables (pre- and post-treatment symptoms) assessed in general observations by the examining physician and the patients themselves. There were no quantified measures of the patients' conditions, either before or after the administration of the drug. There was also no control group (either with a placebo or with no drug) nor any statistical treatment of the results. Further analysis is needed of the differences between the two groups that may have caused the divergent results between them, including better clarification of the "psychosomatic" nature of the younger group's symptoms, in opposition to the organic problems of the older group.

159

Tiller, Perry R., Catechol Amine Excretion in Urine during Simulated Flight, Philadelphia, U.S. Naval Air Material Center, Air Crew Equipment Lab., NAMC–ACEL–456, DDC AD #255, 215 (1961).

Abstract:

Seven subjects (4 pilots and 3 non-pilots) flew a prescribed pattern in a F9F simulator under 3 suit conditions: (1) summer flight suit, (2) the Navy's full pressure suit, pressurized to 0.5 psi, and (3) the full pressure suit, pressurized to 2.0 psi. The non-pilots were given 20 to 30 hours of training prior to the experiment, and the pilots received 5 to 7 hours of orientation in the simulator. During the experiment, subjects were required to fly for 6-hour periods in simulated flight experiences that even included "thunderstorms" and "emergencies." The subjects were tested in each of the 3 conditions. Urine samples were collected prior to and after each experimental trial, and epinephrine and norepinephrine excretions were determined fluorometrically. The excretion of these amines was used as an indicator of stress.

The results showed there was no significant increase of epinephrine or norepinephrine excretion when the subjects wore a summer flight suit. Significant increases ($p < 0.05$) of norepinephrine excretion were obtained, however, when the subjects wore the pressure suit in both conditions. Although there was not a statistically significant increase in epinephrine excretion, there was approximately a 50% absolute increase with the pressure suit.

In flight simulations, subjects have not been reported to undergo the anxiety or emotional stress that is present in actual flight conditions. The author concluded, therefore, that the amine increases observed in this experiment were primarily indicators of physical, not psychological stress and that the subjects in the pressure suit were genuinely suffering from muscular fatigue. Monitoring performance and subjective comments from the pilots also showed that it was more difficult to maintain accurate flight performance when wearing the pressure suit.

This study satisfactorily conformed to required standards of methodology and statistical analysis. A larger sample and a report of the sequence of trials and the intervals between them would have been advisable.

160

Todd, W. R., and Allen, Marilouise, Maintenance of Carbohydrate Stores during Stress of Cold and Fatigue in Rats Prefed Diets Containing Added Glycine, Ladd AFB, Alaskan Air Command, Arctic Aeromed. Lab, TR-57-34, DDC AD # 293, 140 (1960).

Abstract:

Previous data have indicated that rats prefed a diet containing 10% of the amino acid glycine showed higher levels of glycogen storage during the stress of fasting or of administered insulin than animals fed the same diet but without glycine. This study considered: (1) the effects of the stress of (a) cold, and (b) cold accompanied by fatigue, or carbohydrate maintenance (i.e., glycogen storage), in relation to prefeeding diets with and without glycine; (2) the effect of glycine feeding upon glycogen fractions under stresses of (a) swimming and (b) a large dose of insulin; and (3) the effect of glycine feeding upon insulin "utilization" using I^{131} -labeled insulin. The composition of the control diet and of the glycine diet was identical except that 10% of the 54% dextrin in the control ration was replaced by an equal weight of glycine. Half the animals in each experiment were fed the glycine, and half received the control diet. The procedure: (1) (a) In the cold stress experiment 78 male Sprague-Dawley rats, weighing around 200 gm. were placed in individual cages in the cold room at 8° C. The rats were scarificed after various times of cold stress (0, 1.5, 3, 5, 7, 12 hours). Representative samples of the minced liver and of the gastrocnemius muscle were used for the determination of glycogen. (b) In the cold-fatigue experiment 18 rats were made to swim in cold water (14° C.) for three 10-minute periods, divided by two 30-minute rest periods (at 20° C.), for a total stress time of 90 minutes, after which the animals were sacrificed. (2) In the glycogen fraction experiments: (a) 20 rats repeated the swimming procedure and then were killed and tested for the fractions of both trichloracetic acid-soluble glycogen and residual glycogen in muscle and liver tissues; (b) 20 rats were subjected to the stress of insulin administered subcutaneously after 7 to 9 hours fasting. After 5 hours of insulin action they were sacrificed for glycogen fraction determinations. Twenty other rats received no insulin and were killed after 7 to 9 hours fasting. Sixteen other rats underwent no stress and had not fasted when they were killed. (3) In the insulin utilization experiment 10 rats were given subcutaneously a saline solution of a mixture of crystalline insulin and crystalline insulin tagged with I^{131}, maintaining radioactivity at five uc in each dose. At 15 and 30 minutes following injection, the animals were sacrificed and samples of blood, liver, and kidney taken for radioiodine determinations.

The results: (1) (a) Rats prefed diets with glycine maintained carbohydrate stores during the stress of cold at a higher level than did animals prefed the diet without the amino acid. (b) When fatigue was added to the stress of cold in the swimming experiment, liver glycogen levels were over 1% greater in the glycine rats (almost double the level of the control group), although no beneficial effect in the muscle glycogen was evident. (2) (a) The trichloracetic acid-soluble fraction of liver glycogen was more labile than the residual glycogen to the stress of swimming in both glycine- and control-fed rats, but with no difference between the two diets. (b) With the stress of the large dose of insulin, the soluble fraction of both liver and muscle was even more markedly lowered, with glycine feeding tending to lessen the loss. (3) No trend was noted relative to different degrees of "insulin destruction" by glycine- and control-fed rats. This result was taken as inconclusive by the authors, however, speculating on a possible trend at some time other than 15 or 30 minutes after insulin administration.

The data were considered to be additional support for an earlier postulate that glycine prefeeding stimulates glycogenesis during stress, probably mediated through adrenal cortical action.

This was an extensive, well-controlled series of experiments, with precise physiological measurements. No statistical analysis was made, however, and results are reported as arithmetic comparisons among various mean scores. The results of the control groups by themselves may be useful for considering the effects of various stresses upon glycogen storage, incidental to the factor of glycine feeding.

161

Travis, Roland C., et al., Muscle action potentials as a measure of visual performance cost, Illuminating Engineering **46**, 182–187 (1951).

Abstract:

A small series of experiements in varying the level of illumination and reading distance during reading tasks was run with a few subjects. The subject was seated before a small, linoleum-covered table in a ventilated, sound-reduced room, six feet long, four feet wide, and seven feet in height, and covered with aluminum paint with 38 per cent reflectivity. A luminaire capable of holding 20, 42-inch slimline fluorescent lamps was mounted six inches from the ceiling. A louvered shutter two inches below the luminaire, activated by a variable-speed motor, could change the illumination at the table top from 220 footcandles down to 0.2 footcandles within five minutes at the fastest rate and at five hours at the slowest rate. The experimenters decided to use 40 footcandles as the upper limit of illumination, and the shutter control unit was set to change the level at a linear rate from the high to the low level in approximately eleven minutes, a rate slower than the dark adaptation of the eye. Action potentials from the muscles just above the subject's eyebrows were recorded by electrodes placed two inches apart in a headband, integrated over each second of time, and recorded on a continuous tape.

Results: One subject read about 14 per cent faster at a 10-footcandle level than at a 0.2-footcandle level. Two subjects showed greater variability in tension level. Four subjects showed on the average a small increase in tension level during the low illumination periods. Two subjects showed great increases in tension levels due to interest or motivational factors. In one subject the reading rate was apparently not influenced by the illumination level, but there was possibly some effect on muscular tension. Another subject, however, showed no change in tension level, but did read at a faster rate with higher illumination. Moving a book to twice the subject's normal viewing distance caused a marked increase in muscle action potential, which seemed to be independent of illumination level. In one run made with an old book with eight-point type in faded ink on yellowed paper, reading rate changed more than in any of the other tests and was directly proportional to the illumination level, and the physiological cost increased both with low illumination and with elapsed time.

The present results are preliminary, and the authors suggest the following for further investigation: (1) A continuation of the present work. (2) Reading ten-point type in confortable surroundings at low illumination levels for long periods of time. (3) Reading at different illumination levels in a dark surround for long periods. (4) An analysis of industrial and commercial tasks in terms of tension level as affected by illumination.

It must be emphasized that the results and conclusions presented here are quite preliminary and tentative, in that only a few experiments were made and with but a few subjects, and the results were apparently analyzed only by inspection of curves. Experimentation such as the authors suggest is recommended to verify the results.

162

Tucker, Ledyard R., A Rational Curve Relating Length of Rest Period and Length of Subsequent Work Period for an Ergographic Experiment, Princeton University and the Educational Testing Serviee, Inc., Project Number NR 150-088 (DDC AD #42,985) (1954).

Abstract:

A rational function is here developed to relate the length of a rest period and the length of the subsequent work period in a simple ergographic situation. Two subjects were tested on a spring-loaded finger ergograph, one for six sessions and the other for eight. The rate of finger contraction was set at all times at one per second. Finger movement was limited by a

block which the subject had to touch at each contraction. Failure to reach the block ended a work period. Each session of periods began with a warm-up series of three work periods separated by 60-second rest periods. The first experimental rest period followed immediately the last warm-up work period, and work periods alternated with rest periods of varying lengths from thereafter. Each of the ten selected rest periods, of five to two hundred and forty seconds in length, was used once in each session, in varying order, and the subsequent work period length was determined.

The mean length of the work periods following each rest period length was computed for each subject. Mean length of work period plotted against the preceeding-rest-period length showed that as the length of the rest period increased, the succeeding work period also increased in time, but at a decreasing rate of increase, becoming asymptotic at some level. A rational function was developed to represent this relationship. The function yields the general trend of the observed data, but there seem to be some systematic, non-random deviations of these data from the function in its present state of development.

Further work needs to be done in the area opened up by this excellent exploratory study. A more adequate expression of the function needs to be developed. Tests involving more subjects than were used here would not only smooth out the effects of individual differences, but could also investigate such individual variables as age, motivation, sex, or physical condition. Independent variables—environmental factors, drugs, length and frequency of finger movements, for example—could also be studied.

163

Vanderplas, James M., Radar Operator Visual Fatigue: A Summary of Available Evidence and Some Preliminary Suggestions for the Reduction of Visual Fatigue, Wright Air Development Center, AD #62772 (Aug. 1952).

Abstract:

This is a summary of some of the literature on visual fatigue, especially that pertaining to problems encountered by radar operators on long missions. Fatigue is dicussed with respect to the following factors:

A. Visual factors, including illumination both of the object and of the room, contrast, size of objects, and viewing distance;

B. Other general factors, such as motivation, attention and distraction, rest periods and work time, and sleep; and

C. Factors specific to radar scopes—sweep line flickering, changing brightnesses, and eye movements. Possible ameliorative measures to reduce visual fatigue are given with respect to the general illumination, hood design, contrast, viewing distance, motivation, sleep, and rest periods.

164

Vetter, Klaus, and Horvath, S. M. Analysis of physiological tremor during rest and exhaustion, Journal of Applied Physiology **16** (6), 994–996 (1961).

Abstract:

Tremor was recorded for both hands of 14 healthy subjects (7 left-handers, 7 right-handers) of the same age and sex distribution, for 2 minutes by a vibration pickup preamplifier combined with a frequency spectrometer. The subjects were seated and touched the steel stick of the accelerometer with all fingers of the test arm, bent at 90° at the elbow. None of the subjects were under the influence of nicotine, caffeine, or other drugs; and the test situation was in a constant-temperature room kept at 23° C. and 50% relative humidity. The results indicated that the dominant hand exhibited the smaller frequency and the greater amplitude of tremor. An inverse relationship between frequency to increase and decrease simultaneously.

Four healthy male subjects of the same age were also tested before, during, and after an exhausting exercise on a bicycle ergometer. Each subject performed on two successive days by riding the bicycle at 50 cycles per minute against a load of 1,500 kg-m until he could no longer follow the pace—usually between 2 and 4 minutes. All these subjects were right-handed, and kept their right fingers on the recording stick during the entire test. Electrocardiograms were continuously recorded to obtain heart rate. Pre-exercise levels of tremor amplitude and frequency were steady. As soon as the subjects began exercising, tremor amplitude increased markedly (to a mean of 98%) and tremor frequency decreased (by 30%). Both changes are significant at the 0.01 level. The authors state that there appeared to be some correlation of this change to the rate of increase in heart rate (which latter approached 180 beats per minute just before cessation of work), but they do not state what the correlation is. The tremor pattern leveled off in the last 30 seconds of work, returned rapidly toward control values when work was stopped, and was practically at the control levels 7 minutes later. The mean heart rate, however, was 20 beats per minute above normal 7 minute after work cessation.

Although only a very few subjects were used in the exercise experiment, physiological tremor, as it appears to react very rapidly to the onset and cessation of exercise, may be a valuable measure.

165

Vincent, John. Fatigue Comparison Study—Theodolite Operation, Seattle, Boeing Co., Test Report No. T2-3209-38. DDC AD #455,969 (1965).

Abstract:

The azimuth alignment procedure for the Force Modernized (FM) Minuteman missile system uses a theodolite with an eyepiece 32″ above the floor. The previous configuration (MM) apparently placed the eye-piece in a position to be used by a standing man. A test was conducted to determine the effects of the FM position on operator comfort, alignment accuracy, and alignment time. Four theodolite operators (three experienced and one inexperienced) 5′ 8″ to 5′ 11″ in height each made 20 measurements with each of the two configurations on successive days.

Results: (1) The variance of alignment readings was calculated for each operator in each configuration. These results are presented only graphically. Variance appears by inspection to be slightly less for the FM position than for the old MM. (2) The time in hours required to perform the 20 alignments with each system by each operator is also presented graphically. The time for the FM appears to be slightly shorter on the whole than that for the MM. (3) All operators are reported to have complained loudly of discomfort when using the FM procedure, and they evidenced physical strain by constant shifting of position and facial contortions (the latter illustrated by a half dozen photographs).

The author concludes that, with conscientious operators, data of acceptable accuracy can be obtained even under conditions of considerable discomfort. He recommends that a pad be provided for the operator to work on, and cautions that long term morale may be adversely affected using the FM system.

While the experimental design is adequate, the results were apparently not analyzed objectively to determine what differences in errors and time existed between the two configurations; therefore, this study must be rated as poor. Furthermore, no evidence is given of systematic recording or analysis of the operators' subjective feelings.

166

Visscher, Maurice B., and Halberg, Franz, Daily rhythms in numbers of circulating eosinophils and some related phenomena, New York Academy of Science, Annals **59**, 834–849 (1955).

Abstract:

Studies were conducted to test the possibility that factors relating to time of day are critical in determining the level of circulating eosinophils in mice. Under normal conditions, the level varies on a 24-hour cycle. Four days after mice were subjected to a reversal of lighting schedules (with light presented from 6 PM to 6 AM), the eosinophil level cycle reversed.

Fourteen days of continuous darkness did not affect the cycle; but when food was limited to about 2/3 of the calories ingested by mice of the same age when allowed free access to food, there is a complete reversal of cycle, which, so to speak, turns night into day for the mouse when a limited amount of food is available only by day. It appears that the eosinophil cycle is related to activity levels.

Since lighting cycle reversal produced a sharp reversal in eosinophil rhythm, the role of the eyes was tested by bilateral optic enucleation. Using serially independent sampling, the control animals had a normal cycle for the duration of the study, while the blinded animals had an inverted cycle at the 39th postoperative day and it reversed again at the 47th. At 80 and 90 days, there were no significant differences between day and night levels. Changes also occurred in body temperature cycles, as measured by rectal thermistor—mean cycle shortens by ½ hour during the first month, but is more erratic during the second and third—and these obviously were related to the eosinophil cycle. Lighting effects through the eyes appeared to be the dominant normal synchronizer of the 24-hour cycle in mice. The fact, however, that congenitally blind mice show a solar day rhythm and that it is inverted by a reversal of lighting if "seeing" mice are in the same room and not otherwise, indicates a dependence in such blind mice upon sense organs other than the eye. This does not answer the question of whether the basic eosinophil-cycle phenomena is inherited or acquired. Removal of the adrenal glands in mice and untreated cortical insufficiency in man appear to abolish the characteristic cycle.

This is an excellent study of a phenomenon—daily variation in eosinophil level—which can account for some anomalies in human fatigue experiments.

167

Vodolazski, L. A., Zolina, Z. M., and Kosilov, S. A., Electromyographic investigations on muscle activity in man during prolonged industrial work, Fiziologicheskii Zhurnal imeni I. T. Secheneva (USSR) **45** (9), 1045–1052 (1959).

Abstract:

Variations of efficiency throughout a working day are demonstrated in tracings of action currents of muscle and heart recorded continuously in subjects engaged in conveyor operations by means of special techniques without interfering with their work. The following changes were found to occur in the beginning of a working day:

(1) decreasing average frequency of action currents,
(2) rising mean amplitude of action currents,
(3) reduced time of development and duration of tetanus,
(4) rising total mean amplitude of action currents, and
(5) growth of the factor of concentration of excitation.

By the end of a working day, the following changes were found to take place in typical cases:

(1) average frequency of action currents was higher,
(2) mean amplitude of action currents was diminished,
(3) time of development and duration of tetanus became longer,
(4) total mean action current amplitude was diminished, and
(5) the factor of concentration of excitation was reduced.

These EMG changes, as well as a number of other physiological indices, demonstrates that this particular belt conveyor operation involves strenuous work of a fatiguing nature. (Authors' Abstract.)

168

Vogel, James A., Hansen, James E., and Harris, Charles W., Cardiovascular responses in man during exhaustive work at sea level and high altitude, Journal of Applied Physiology **23**, 531–539 (1967).

Abstract:

Twenty-four young men were divided into three groups of eight, one remaining at sea level, another transported abruptly to an altitude of 4,300 meters (Pikes Peak, 14,100 feet), and the third transported to Pikes Peak gradually with one-week stops at 1,610 and 3,475 meters (5,200 and 11,400 feet, respectively). Each group of 8 was further divided in half, 4 men being assigned to a reduced physical activity program, and 4 to an increased physical training program. All subjects were measured initially at sea level. The men who went to altitude were measured between their first and fourth day there, and again between the fifteenth and eighteenth days. After 4 weeks at altitude, they returned to sea level and were measured within 5 days, along with those who had remained at sea level. Each measurement run consisted of a 10-minute sitting rest period, 3 levels of uninterrupted upright bicycle ergometer exercise (at 367, 428–734, and 673–1530 kilogram-meters of work per minute) resulting in exhaustion in approximately 30 minutes, and then 30 minutes of sitting recovery. Arterial blood pressure was recorded continuously from catheters inserted into the brachial artery and a forearm vein, and heart rate in beats per minute was counted directly from the blood pressure tracing. Cardiac output was determined by the dye-dilution technique during each portion of the test run.

As demonstrated by analysis of variance, cardiac output expressed on a body weight basis was affected by change in altitude ($p < 0.01$) and rate of ascent ($p < 0.08$), but not by physical conditioning. At altitude, cardiac output increased over sea level values at rest (12%), during all levels of exercise (16–18%), and after 10 minutes of recovery (20%). Heart rate was affected very significantly by altitude ($p < 0.01$), only marginally by physical training ($p < 0.10$), and insignificantly by rate of ascent ($p < 0.20$). Resting heart rate was 18% higher than the initial sea level value during the entire stay at altitude, and was 10% lower than the initial value upon return to sea level. Maximum attainable heart rate was less at high altitude than it had been at sea level. Stroke volume was significantly influenced by altitude ($p < 0.01$) and by rate of ascent ($p < 0.05$). The shape of the stroke volume response curve to exercise was also affected by altitude. At sea level (both before and after the 4 weeks at altitude) as heart rate increased with exercise, stroke volume increased, plateaued, and then decreased. At altitude, however, stroke volume increased nearly linearly throughout exercise. Systolic blood pressure was affected significantly by change in altitude ($p < 0.01$), rate of ascent ($p < 0.05$), and physical training ($p < 0.05$); and diastolic pressure changed with altitude similarly to the systolic both in direction and magnitude. Mean arterial blood pressure was significantly influenced by altitude ($p < 0.01$) and physical conditioning ($p < 0.05$), but not by rate of ascent. Total peripheral resistance in the circulatory system decreased significantly ($p < 0.01$) and the amount of work done by the left ventricle of the heart increased significantly ($p < 0.01$) with the change in altitude. All measurements except heart rate returned to or near sea-level values by the third week at 4,300 meters.

Hansen et al. (1967), discuss other aspects of this study.

169

Walk, Dieter E., and Sasaki, Edwin H., Procedure to Assess Energy Expended during a Short-Period Task, Wright-Patterson A.F.B., Ohio. Aerospace Med. Res. Labs, AMRL TR–65–205, DDC AD #637,692 (1965).

Abstract:

A procedure was developed for determining energy expenditure in tasks of very short duration, and was applied in a reduced gravity environment. The energy expended in a 12-second rowing task was measured on the basis of expired air samples collected under three conditions: (1) 30 seconds of rest, (2) 12 seconds of work (rowing at a rate of 30 strokes per minute), and (3) 15 seconds of recovery. Preceding each series of these three conditions was a 3-minute period of inactivity. The conditions were repeated 10 times, and the subject's expired air was accumulated separately in three Douglas bags to obtain a 5-minute collection for rest, a 2-minute collection for work, and a 2.5-minute collection for recovery. This series of 10 runs was repeated during four consecutive days for each of four different environments: (1) laboratory, (2) aircraft 1G level flight, (3) aircraft 2G–1G–2G bank maneuvers, and (4) aircraft 2G–0G–2G parabolic maneuvers. There was one sub-

ject, 23 years old, evidencing good physical health and complete well-being in zero G.

The results: The gross differences of the volumes of air, oxygen, and carbon dioxide exchanged in condition 1 (rest) compared to condition 2 (work), and condition 2 compared to condition 3 (recovery), showed the body reacted to a change in physical activity and returned to a state of equilibrium much more quickly than previously reported in the literature. The volumes of expired air, oxygen, and carbon dioxide in each condition (rest, work, recovery) were similiar in the four environments, and the specific effects, if any, of the differential gravity levels were negligible and unsystematic. One reason given by the authors for this was that the rowing task was hydraulic and, therefore, not weight oriented, i.e., the amount of force required on the oars was the same regardless of the environment (gravity level). The amount of physical work done in the experiment was calculated (3150 ft. lb.), as was the mechanical efficiency (23.9%). The authors concluded that the comparability of these values with previously reported and accepted values lent validity to the results.

The experimental apparatus was carefully designed and brought forth the desired precise physical measurements. The experiment as a test of this apparatus, by comparison with accepted values, was satisfactory. However, the experiment as an exploration of variable relationships had several defects. No statistical analysis was performed on the results, which are reported merely by inspection of gross differences. The rowing task was poorly selected as a work task in various gravity levels, since, as the authors pointed out, the amount of force required on the oars is independent of gravity level, and thus the variable of environment was a priori rendered irrelevant by the experimental design itself. Also, the sample was small (one subject), and experimentation with a group of subjects will be necessary in future research.

170

Walker. Norman K., and Fricker, Charles, The Use of Tracking Tests as Indicators of Stress, Annual Progress Report, College Park, Univ. of Md., Inst. for Behavioral Research, DDC AD #276,698 (1962).

Abstract:

Studies were made to determine whether certain tracking tests could be used as accurate indicators of stress. Systems with substantially fixed targets were considered, as opposed to the moving targets studied in previous research. It was found that if a human operator was asked to return an indicator to a fixed position by moving a control stick, the indicator deflection being, for instance, the second integral of the control stick displacement. then the response was a continuous oscillation about the null position. The error could be due only to the man himself, and under suitable conditions would be in fixed ratio to the stick input. It is known that stress will cause degradation of operator performance, so stress could be directly compared numerically by comparing error ratios. Analog computation equipment was assembled which gave a direct readout of the mean modular error, and great care was taken to eliminate drift and zero errors.

Preliminary experiments were conducted with the apparatus with subjects under various conditions of stress. The experimental conditions and results were: (1) Four subjects performed a two integrator tracking task in seven one-minute trials, at 20-minute intervals, under the "stress" of alcohol (one Manhattan every 20 minutes). In general, the effect of alcohol in each case was to cause a steady improvement in performance. (2) One subject performed the test under fatigue stress, (continuous tracking for one hour), and evidenced both degradation of performance and variable improvements. (3) One subject took the test under the stress of sleep deprivation (24 hours without sleep) and showed performance degradation. The authors concluded that the results demonstrated that the equipment was effective and simple to use, and that the readout of error was convenient and apparently capable of detecting quite small changes in performance. The various stresses were seen to cause noticeable changes in performance.

This report was a progress report on a pilot study. The experiments were only exploratory preliminary runs, not intended by the authors to satisfy rigid requirements for controlled experimentation. and had, therefore. a small sample. short duration, and brief analysis of data. There seems to be evidence at this point that the apparatus is, as claimed, a sensitive recorder of tracking performance behavior. Whether such a sensitive performance measure can also be, as claimed, an accurate measure of *stress* must be further and more adequately tested, employing it in known and certain conditions of stress.

171

Walster, Bill, and Aronson, Elliot, Effect of expectancy of task duration on the experience of fatigue, Journal of Experimental Social Psychology **3** (1); 41–46 (1967).

Abstract:

An experiment tested the hypothesis that if an individual feels that he must perform N trials of a fatiguing task. he will experience a greater increase in fatigue during the Nth trial than will an individual who has performed the same task but feels that he still has more to do. Twenty volunteers from an introductory psychology course were told that they would participate in a study of the relationship between eye fatigue and absolute visual threshold. While dark-adapting in red light for one hour, each subject answered a questionnaire about his pre-experiment fatigue state and checked the appropriate point on a linear scale which went from zero (I feel now "as fresh as I have ever been") to 13.5 ("as tired as I have ever been"). Next he would perform a fatiguing task—marking Xs in the squares of graph paper to a metronome beat at the rate of one per second for ten minutes. Following this task, the subject again checked the subjective fatigue scale, and then had his visual threshold measured by presentations at varying intensity of a square white light during a ten-minute period. Half the subjects were led to expect that they would be required to perform these two tasks for three consecutive trials. and the other half for five trials. The experiment was stopped for each subject at the end of three trials.

It had been predicted that the subjects in the short-expectancy condition would display a sudden increase in fatigue during trial three while the subjects expecting to complete five trials would not. An interaction F contrasting conditions and trials one and two versus trial three was significant ($p<0.001$), indicating that this was true, as measured by the subjective-fatigue scale. Although earlier work by Spencer and Cohen reported a correlation of 0.90 between a person's visual threshold measure of fatigue and how long he had slept the previous night, the correlation in this experiment was −0.10. Analysis of the visual threshold data over the three trials indicated no relationship to fatigue. (These data are not presented in the paper.)

Although the subjects are reported to have been assigned randomly to the conditions, there appear to be rather large differences between the ratings of subjective fatigue made by the two groups for the premeasure period and the first two trials. Any replication of this experiment should include a sample of greater size and more varied composition than that used here.

172

Walters, J. D., Chronic fatigue: metabolic and nutritional aspects, Journal of Applied Nutrition, **17**, 126–140 (1964).

Abstract:

Of 650 consecutive cases seen by the author, a California medical doctor, 615 (or over 94%) complained of fatigue. In this latter group were 378 females and 237 males. Children under 5 years of age were excluded. The foregoing is the extent of the statistical treatment in this article. The author found that fatigue seemed to be associated with such factors as: overwork, under-exercise, over-exercise, hereditary traits. indoor living, monotonous routine work, nervous tension and anxiety, inadequate and irregular rest and sleep, chronic illnesses and disorders, occupation, drugs, excess tobacco and alcohol, and low standards of hygiene.

Following some generalizations and personal observations concerning chronic fatigue and aging, are 8 case histories. The method of selecting these particular 8 for presentation is not given, and, from inspection of the case-history numbers (the lowest is #8642, the highest is #12,108), it would appear that they were not extracted from the consecutive run of 650 cases that the author mentions near the beginning of his report. The cases do represent a range of ages and sexes. Each patient had a great variety of complaints, and extensive testing revealed a large number of physiological and physical disorders.

Treatment in all 8 cases consisted mainly of dietary prescriptions—a diet of 40% protein, 30% fat, and 30% carbohydrate, with no more than 25% cooked food (a diet followed by the author himself for 30 years), various and numerous supplements, such as virgin cold-pressed oils, sprouted grains, and concentrated liquid of unheated organs. The treatment worked beautifully in all 8 cases.

173

Ward, Richard J., et al., An Evaluation of Human Performance during Exposure to Elevated Heat and Humidity, Univ. of Washington, School of Medicine, Contract DA-49-193-MD-2231, DDC AD #471,721 (1965).

Abstract:

Forty-four soldiers participated in an evaluation of performance during exposure to increased heat and humidity. Determination of performance capability was made by measuring the flicker fusion response (FFR) of each subject. FFR was determined by increasing the rate of flashes in steps until the sensation of fusion was produced. Each subject served as his own control. The control determination of the FFR for all 44 subjects was taken in a room at 76° F. and 40% humidity. Twenty-nine subjects were then placed in a room at 82° F. and 70% humidity for three hours. After two hours, they were subdivided in two groups. The 15 subjects in Group I were given an unannounced difficult civics test, and told that the results would be very important to them personally. The 14 subjects in Group II were required only to remain in the room for the additional hour. After three hours, FFR was again determined for the two groups. The remaining 15 subjects (Group III) were given the same unannounced civics test, but under identical conditions of comfortable temperature and humidity as when the control FFR was determined. After the test, FFR was again determined for Group III.

Group I (mental stress plus uncomfortable environment) showed a decrease in FFR, significant at $p < 0.01$. Group III (mental stress only) showed a decrease in FFR, significant at $p < 0.05$. Group I differed statistically from Groups II and III at $p < 0.01$. It was concluded that one's mental capabilities are blunted by mental stress and hot, humid environmental conditions. The blunting in this experiment exceeded that previously reported after medication with a commonly prescribed soporific. The adverse environmental conditions themselves caused moderate depression of function. Mental stress alone caused less significant depression of function. It was noted that the temperature and humidity ranges studied in this experiment were not excessive and are commonly found.

This was a very well designed and reported study, and statistical analysis was applied to the data. The authors took the FFR measurement for granted and with it investigated the effects of certain types of stress. Yet the experiment may be valuably viewed in reverse as well, and may serve to demonstrate the workability of the FFR itself, i.e., that FFR does vary significantly for subjects under stress.

174

Warren, Bruce H., et al., Determination of inflight biochemical responses utilizing the parotid fluid collection technic, Aerospace Medicine **37** (8), 796–799, DDC AD #643,883 (1966).

Abstract:

Parotid fluid samples were collected from 11 volunteer subjects during 57 clear weather, daytime, cross-country flights [illegible] back cockpit of NF-100F aircraft. Subjects consisted of pilots and nonpilots all of whom were in a nonpiloting capacity during the experiments. Parotid fluid samples were also collected on subjects during a normal nonflying duty day.

The plastic collecting device utilized in these experiments was provided with an acrylic bite block moulded to the individual bite of each subject. This allowed easy and rapid self-positioning of the device over the parotid duct opening. All parotid fluid samples were analyzed for free 17-OHCS levels.

The nonflying day mean values for free 17-OHCS levels were essentially the same for F-100 pilots and nonpilots. F-100 pilots evidenced rises of free 17-OHCS during preflight, takeoff, and landing portions of flight which were considerably above the nonflying day mean value as well as above the mean values of nonpilots during corresponding portions of flight. (Authors' Abstract)

Although tests of significance appear to have not been made for the differences between pilots and nonpilots, this is a very good preliminary study, and the method appears to be a valuable one.

175

Watt, D. N., and Innes, L. G., Decrement in Maximum Applied Arm Forces Exerted on a Stick-Type Control Column, Toronto, Canada, RCAF Institute of Aviation Medicine, Report #63-RD-4, AD #434,876 (1963).

Abstract:

Arm forces were applied over a 60-second period to a control column. The 12 subjects were men between the ages of 22 and 38, from the staff of the Institute or volunteer airmen. Each subject was strapped in a mock-up pilot's seat with shoulder harness and lap belt attached. The subject exerted push and pull forces on a stick-type control with both hands and with each hand singly, in two directions of movement, forward-back and laterally. The subject was instructed to apply and maintain the maximum force of which he was capable. The mean, standard deviation, and range was computed in pounds of force for all conditions at the initial application of force and at 15-second intervals up to the duration of 60 seconds. The measure of "fatigue" for this study was the percentage decrement of applied force from the beginning to the end of the 60-second period.

Results: (1) Generally, the two-handed operation of the control in both directions showed less decrement in applied force than either the right or left hand alone, with the exception that push forces for both hands and right hand were almost identical in the lateral condition. (2) There was a tendency for the right hand, pushing or pulling, to have a higher percentage decrement than the left hand. (All subjects were right-handed.) (3) There was a tendency for push forces in both directions in all conditions examined to have a higher decrement than corresponding pull forces. Also, mean push forces were greater than pull forces for each hand alone but were similar for both hands.

A full complement of graphs and tables supplement the text, enough to allow the reader to apply his own statistical tests for significance to the data, but the authors omitted statistical analysis entirely. Otherwise, the methodology was adequate and comprehensively reported.

176

Webb, Wilse, B. and Wherry, Robert, Jr., Vigilance in Prolonged and Repeated Sessions, Pensacola, Florida, U.S. Naval School of Aviation Medicine, Bureau of Medicine and Surgery, AD #262570, (1961).

Abstract:

Inter- and intra-subject response characteristics were investigated for prolonged and repeated sessions of monitoring a simple signal. Three seamen between the ages of 19 and 21 monitored a three-second auditory signal, occurring at varying intervals against a continuous background, in five nine-hour sessions. The monitored signal was further varied to permit study of the effect of direction of signal change, the degree of signal change, and the interval of signal input.

The results showed: (1) no significant change in response

over the five sessions for all subjects, (2) an increasing latency of response within sessions, and (3) an increase in variability of response for two subjects and a decrease in variability for the third.

The most critical defect of this study is its limitation to three subjects, thus almost nullifying the otherwise valuable and detailed discussion of results and the statistical treatment. Yet the methodology is good for the study of long-duration responses when sensory-motor fatigue is minimized, and the study should be replicated with a more adequate sample.

177

Wendt, Hans-Werner, Achievement Motivation and the Problem of Energy Mobilization and Fatigue, Wesleyan University, ASTIA AD No. 25607 (1953).

Abstract:

The general problem assessed was that of motivation effects on performance. Specifically, the study was concerned with (a) the problem of defining suitable measures that will approximate reasonable "valid" indices for such complex variables as motivation, performance, effort, and fatigue; and (b) investigating some of their interrelations. Coupled with this, the relative change of the critical fusion frequency (CFF) was employed to determine if it had any fatiguing effects or affected motivation. The experimental procedure consisted of seven parts: (a) a questionnaire covering general background data; (b) a four-picture measure of the need for achievement (TAT); (c) determination of CFF; (d) an arithmetic task in an "unscheduled" situation for 25 minutes; (e) an arithmetic task in a "Scheduled" situation for 25 minutes; (f) ratings of the task on three five-point scales in terms of "interesting," "boring, and "fatiguing; (g) determination of CFF. The subjects employed were 38 high school juniors and seniors and 14 college students; but the results of the two groups were not compared as it was felt that the college subjects, by virtue of their desire to be in college, exhibited more motivation.

The data were plotted graphically first and then comparisons between Low, Medium, and High performance groups were made by use of two-tailed t-tests with levels of significant percentages being based on arc sine transformations.

It was found that: (a) the higher the motivation, the better the performance on the mathematics task. (b) Those with low motivation improved performance on those tasks which were paced, i.e., scheduled. (c) The CFF determination dropped more for the less motivated subjects, as the more motivated directed more attention and effort to their tasks. (d) Motivated subjects performed best on unscheduled tasks, their productivity dropping closer to the unmotivated group under conditions of pacing. (e) Accuracy was higher in all cases for the motivated subjects. (f) Distinction between "intrinsic" and "extrinsic" motive components was proposed in order to account for previous findings that experimental stress situations frequently does not lead to noticeable performance decrements. (g) The validity of CFF changes as an index of fatigue was seen restricted to: (1) conditions for which a lack of motivation and subsequent failure to energize physiological adaptation mechanisms, are the chief characteristics; and (2) possibly to a certain range of "medium motive intensity. Sufficient evidence was not found to reject the null hypotheses that: (a) Subjective ratings of fatigue and CFF changes need not be related; and (2) Subjective ratings of fatigue and n Achievement need not be correlated.

The study was approached with good methodology, and adequate support for the findings is found in the text. Determination of the fact that motivation results in high efficiency of performance, especially in unscheduled periods, and is unaffected by the CFF. leads to the question of how to instill high motivation in order to obtain maximum efficiency and accuracy. The restrictions proposed for the use of CFF as a measure of fatigue are also important.

178

Whittenburg, John A., A Further Experimental Investigation of Perceptual Efficiency During Sustained Vigilance, Indicators of Behavior Decrement, Series TR–17, College Park, Maryland, Univ. of Maryland, Dept. of Psychology, DDC AD #31,286 (n/d).

Abstract:

The effect of sustained vigilance on perceptual efficiency was investigated, using the Mackworth Clock Test (where subjects are required to attend to discrete movements of a pointer on a clock face and to signal at long and irregular intervals whenever the pointer moves twice the length of its ordinary progressive movements).

Thirteen male college students served as subjects. Each subject performed twice under two experimental conditions using the Mackworth Clock Test. Under condition A, the subject was required to respond only to the occurrence of the variable stimulus (the double jump of the pointer). Under condition B, the subject was required to respond to both the variable stimulus and the standard stimulus (single jump). Each subject was tested for approximately three hours under each condition. A counterbalanced ABBA order was employed to estimate transfer effects. Three dependent variables were employed: (a) errors of omission (failing to detect the presence of the variable stimulus), as a measure of perceptual efficiency, (b) critical flicker frequency (detection of changes from fused to a flickering state and vice versa), as a measure over time of fatigue of the central nervous system, (c) stress experience inventory (34 multiple-choice items in a questionnaire), as a measure of the subject's personal feeling of stress in the experimental situation.

Large individual differences in the errors of omission were reported. The existence of these large variations tended to cancel any possible mean differences between half-hour periods and between condition A and condition B. The analysis of the mean differences and variance differences for both conditions failed to reveal any systematic trends or order among the data for errors of omission, and thus no significant conclusion could be made concerning perceptual efficiency as a function of time on the task.

Under condition A there resulted a statistically significant decrease in the CFF mean thresholds, but no such significant change in situation B. There were varying degrees of relationship among the three dependent variables. There was a statistically significant relationship between CFF and both of the other measures, but in condition B only. The author concluded that interrelationships among the dependent variables suggest some possible relationships exist among the measures but in an extremely complex manner not discernible from the present analysis.

The major conclusion drawn from the experiment was that the lack of consistent results and the presence of large individual differences constitute sufficient cause for abandoning this technique as a potential dependent variable in future investigations of perceptual efficiency under sustained vigilance.

This is an excellent study, extremely well reported. The author gives a full and precisely detailed presentation of background information, his experimental methodology, statistical analysis, and conclusions. Tables, graphs, and the complete "Stress Experience Inventory" are included. Unfortunately, he makes no further suggestion for research beyond abandoning the present technique.

179

Whittenburg, John A., Indicators of Behavior Decrement: Review of the Literature on Measures of Tonus and Tension as Related to Fatigue, TR #2, Department of Psychology, University of Maryland, ASTIA AD #31302, Feb. 25 (1952).

Abstract:

This survey of the literature on tension and tonus includes a 77-item bibliography, and was made to determine the feasibility of using some measure of muscular tension as a dependent variable in connection with the general problem of behavior decrement. The literature is discussed and evaluated according to type of method used, and the method involving the measurement of electrical properties of the muscle is found to be the most appropriate. However, due to problems of technique, apparatus, and time necessary for adequate information on the usefulness of this measure as an indicator of behavior decrement, it is suggested that tension and tonus be eliminated as a possible variable in this study.

180

Whittenburg, John A., A Study of Three Measures of Perceptual Efficiency During Sustained Vigilance, College Park, Md., Univ. of Md. Dept. of Psychol., Tech. Rept. #14, DDC AD #31 289 (1953).

Abstract:

The effects of sustained vigilance on perceptual efficiency were investigated using the Mackworth "Clock Test." The attempt was made to test the reliability and generality of Mackworth's previous findings and also to explore any differential results between male and female subjects. Twelve female and 15 male college students and instructors served as subjects. The task involved a "clock," 10½" in diameter, with no scale markings or reference points, on which a pointer moved in discrete forward jumps every two seconds, moving the tip a distance of ½". At long and irregular intervals the pointer moved twice the usual distance. It was the task of the subject to perceive these double jumps of the pointer and to respond by pulling two switches, one which measured response time and the other which counted the number of responses. There was initial practice period. In the experiment, each subject was tested for a continuous two-hour session under conditions of relative isolation. The double jumps of the pointer occurred only 12 times each 30-minute period, at varying intervals. Three performance measures were obtained: (a) response time (time between the presentation of the double jump and the response of pulling a switch, (b) errors of omission (failure to detect the double jump and to respond within 8 seconds), and (c) errors of commission (responding when no double jump occurred).

The results: (a) Mean scores for both male and female subjects showed a significant decrease in perceptual efficiency after the first half hour as measured by errors of omission. During the last hour, the female subjects made significantly fewer errors of omission than the male subjects. Errors of omission proved to be a relatively reliable measure for the male subjects, but not for the female subjects. (b) The measure involving errors of commission was of little value since contributions to this measure were made by very few subjects. The majority of subjects either did not exhibit any errors of commission over the two-hour period or committed only very few. (c) No definite conclusion could be made concerning the response-time measure, since a variable error was present during the major part of the investigation, and accurate data were obtained from only 11 subjects, four male and seven female subjects. Analysis of these limited data revealed a rapid increase in response time after the first half hour for both groups. the increase being statistically significant for female subjects. (d) The position of the pointer on the clock face at the time of double jumps did not significantly affect results. (e) The length of the time intervals between double jumps did not significantly affect results. (f) There was some indication that a high positive relationship existed between errors of omission and response time for the male subjects. A lower positive relationship existed for female subjects.

On the basis of errors of omission, this experiment substantiated that of Mackworth. The general conclusion was that perceptual efficiency, as measured by errors of omission and response time, may serve as useful measures of behavior decrement under conditions of sustained vigilance.

This was a well conducted experiment, comprehensively reported and analyzed, employing excellent statistical techniques. An extensive introductory section comprises half the report, discussing previous research and justifying the importance and feasibility of the measures employed in the present study.

181

Whittenburg, John A.. and Weiss, Edward, Indicators of Behavior Decrement: Review of the Literature on Olfactory Sensitivity as an Indicator of Systemic Fatigue. Department of Psychology, University of Maryland, TR #6, ASTIA AD #31306. April 30, (1952).

Abstract:

The literature on olfaction, with emphasis on techniques and important variables, in reviewed to determine the feasibility of using some measure of olfactory sensitivity as an indicator of systemic fatigue. Two major problems are encountered: the dimensions of the olfactory stimuli and the dimensions of olfactory sensation. Various classifications of odors are presented and their deficiencies are discussed in terms of the lack of data and methodologies concerning the olfactory process. Various conditions which alter olfactory sensitivity are discussed and some are given in tabular form, and techniques used in olfactory research are evaluated. Conditions which have been shown to alter olfactory sensitivity include obnoxious odors, brain tumors, certain drugs, diseases of the parotid gland. diurnal variation, ether, ethyl alcohol, fasting, head cold, menstruation, smoking, sugar, and supratentorial diseases. The techniques discussed include Zwaardemaker's olfactometer, Elsberg's "blast" technique, Wenzel's "stream" technique, and Foster's dirhinic stimulator for free or controlled sniffing.

The author concludes that both the "blast" and the "stream" techniques should be tried, to determine a possible relationship between systemic fatigue and olfactory sensitivity.

182

Wilbur, D. L., Clinical evaluation of fatigue and nervousness: diagnosis and treatment, Medical Clinics of North America, **37**, 1785–1802 (1953).

Abstract:

The author presents a generalized discussion of acute. recurring, and chronic fatigue, as displayed by patients in the course of medical checkups or visits to their physician. The physician is advised of the nature and various causes of fatigue and nervousness, methods for diagnosis of functional and organic illnesses, and procedures for treatment by organic, psychological. and somatic means. The entire discussion is on the most general and often subjective level, with no quantification of the bases for discussion or recommendation presented—not even case histories.

183

Williams, Harold L., Kearney, Ometta F., and Lubin, Ardie, Signal uncertainity and sleep loss, Journal of Experimental Psychology **69** (4), 401–407 (1965).

Abstract:

This study was designed to further support previous findings that performance on a vigilance task designed with high signal uncertainty was greatly impaired during sleep loss, although a redundant task showed no deterioration. Fifty-two men (ages 18–45) served as subjects. They were divided into two groups: Group 1 consisted of 24 Ss who were tested individually; Group 2 consisted of 28 Ss tested in groups of four whose oral temperatures were taken at the beginning of each session. The task consisted of pressing a response key each time a red light flashed during one of three task variations: (1) a standard task (S) presented eight red signals out of 30 stimulus lights in a determined series; (2) a redundant task (R) presented eight red signals after 22 stimulus lights; (3) an uncertain task (U) presented eight red signals in a random manner over 30 stimulus lights. The tape for each task consisted of 600 stimuli which ran at a rate of one light per second for 10 minutes. A three-to-five-day period to establish base-line performance was followed by two days of deprived-sleep performance and then three days of recovery performance.

Results: (1) All tasks were sensitive to sleep loss, with the U task showing greatest performance decrements. One night of recovery sleep was required to return the performance level to the base-line. (2) After one night of sleep loss, the S and R tasks showed increased errors after seven minutes; the U task after three minutes. After two nights of sleep loss, omissions increased rapidly following two or three minutes of work. (3) Those subjects tested in groups (Groups 2) exhibited less

sleep-loss impairment than Group 1. (4) No relation was found between oral temperature and errors of omission during sleep loss. (5) There was no significant interaction between signal uncertainty and task duration.

In the discussion, the authors noted that previous findings to the effect that increasing task uncertainty lowers the efficiency of the sleep-deprived S were supported. The lapse hypothesis was associated with sleep loss and performance, with mention of the possible effects that task interest may initiate.

This was a well executed study, clearly developed and with thorough statistical treatment of the findings.

184

Williams, Harold L., Lubin, Ardie, & Goodnow, Jacqueline J., Impaired performance with acute sleep loss, American Psychological Association, Inc., Psychological Monographs: General and Applied, **73** (14) (1959).

Abstract:

This study attempted to identify and measure the relationship between the sensitive aspect of performance on any task and sleep deprivation. The results were drawn from two studies, one in 1956 (24 Ss) and the other in 1957 (50 Ss). Both used controls with no sleep loss and experimental groups with 72–98 hours of sleep loss. The experimental design consisted of 11 days: days 1–4, base-line performance, days 5–8 measured sleep loss, and days 9–11 were recovery days with normal wake-sleep patterns. Subject-paced and experimenter-paced tasks were used—the S-paced tasks being graded on speed and the E-paced tasks on accuracy. S-paced tasks consisted of reaction-time tasks, task durations, adding tasks, communication tasks and concept-attainment tasks. E-paced tasks consisted of vigilance tasks with varying motivational conditions, tasks with more complex responses, and information-learning tasks. A final phase concerned analyses of the EEG alpha amplitude and sleep loss.

Results indicated: (1) In the S-paced tests, the consistent results were a change in the speed or rate of performance, but not in its accuracy. These changes in speed stemmed primarily from an increase in the frequency and duration of lapses, and the unlimited response time which allowed for the delay of a response of the correction of errors, which resulted in a sacrifice of speed for accuracy. (2) In the E-paced tasks, the incidence of errors was found to be mostly affected by the length of time during which a task continued without interruption and without a change in the stimulus-response conditions. With increased loss of sleep, errors occurred sooner and sooner after the start of a session. (3) A decline in the EEG alpha amplitude was observed with increasing sleep loss; and errors of omission on an auditory vigilance task were consistently associated with less alpha than were other responses.

This is a good study and goes into much detail on the various measures and tasks that were performed. Adequate statistical treatment is provided for the results. A further study by Williams, Kearney and Lubin (1965) deals with the same basic problem and performance predictability.

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Winsmann, Fred R., and Daniels, Farrington, Pack Carrying in the Desert, U.S. Army Quartermaster Research & Development Center, Natick, Massachusetts, TR No. EP–28, DDC AD No. 106661 (1956).

Abstract:

This study reviews three reports (1952, 1953, 1954) concerned with the effects of various types of desert terrain on the energy cost of carrying loads of different weights representative of loads the combat soldier might be expected to carry. The surfaces studied included level hard surface, level sandy surface, and sandy dune slopes. Pulse rates, rectal temperatures and oxygen consumption were measured as indicators of stress. The Douglas bag method for collecting respired gas was used, and samples of the collected gases were analyzed by the Haldane method. It was found that a 40-lb pack, carried at a speed of 2.5 mph continuously for a half hour was the maximum limit in a sandy area of desert. Anything beyond this load causes excessive physical fatigue and stress and would result in limiting the soldier's combat ability. Statistics presented included two-way analysis of variance and means. Recommendations section points out problems for future research that were noted in the reports. This is a fairly good review and consolidation of the work done on the problem.

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Winsmann, Fred, Vanderbie, J. H., and Daniels, F., Energy Costs of Wearing Armored Vests and Carrying Pack Loads on Treadmill, Level Course, and Mountain Slopes, Lawrence, Mass., QM Climatic Res. Lab., Env. Prot. Branch, R. #208, DDC AD #21,004 (1953).

Abstract:

Research was conducted on the human physiological response to load-carrying. The energy cost of wearing an 8-lb, laminated nylon, armored vest was measured while subjects were walking, with and without a 40-lb pack load, on a treadmill, on a level course, and climbing slopes of from 3 to 18 degrees. A group of seven subjects (average age, 23.5 years), were variously used in the following experimental conditions: (1) In a constant temperature room (70° F.) six subjects walked on a motor-driven treadmill at 3.5 mph for 30 minutes twice daily for five consecutive days. Five trials were with, and five without, vest armor. The same technique was used for the comparison (with seven subjects) of the energy cost of carrying a 40-lb load with and without the 8-lb vest, and for comparing (with six subjects) the energy cost of walking with the vest on to walking with the same weight of 8 lbs carried on the back. (2) On a level cinder track, four subjects walked at a rate of 3.5 mph, using Douglas bags for the collection of expired air. (3) During five days on Mt. Whiteface, N. H., three subjects walked over a course of 2.34 miles, requiring approximately one hour to complete, and during which three energy expenditure measurements were made, using Douglas bags. Slopes on the mountain were selected to provide a 400-yd course on a slope of three to four degrees, a 300-yd course of six degrees, and a 200-yd course of 17.5 degrees. The speed was not controlled, but was measured. Comparisons were made between the cost of climbing the slopes with and without the armored vest, and between the 40-lb pack with and without the armored vest.

Metabolic rates were expressed as cc O_2/min and also as Cal/m^2/hr. Oxygen consumption was measured with a closed system Tissot spirometer, in experimental condition (1) between the 20- and 30-minute point of each walking period. A measurement of sweat loss was the change in nude body weight.

The results: The armored vest imposed a measurable increase in metabolic rate when worn over the fatigue uniform. These increases became greater as the steepness of the slope increased. The extra load and binding effect of the armored vest was of greatest importance at high activity levels, such as rapid climbing over a steep grade. Wearing of the vest under the pack had a negligible, or, perhaps, even favorable effect on carrying loads on the 3- and 6-degree grades in some individuals, but on the steep slopes it caused an increase in the metabolic rate about equal to that imposed by the vest alone. It was not demonstrated that a load carried as a vest with a wide distribution and balance of the weight around the center of gravity of the body was significantly more efficient than carrying this same weight of 8 lb in a pack-load distribution. Interference with heat loss is expected by the authors to be the important limiting factor for use of the vest.

This was in general an adequately designed and reported experiment, with statistical analysis applied (but not consistently) in the interpretation of results. However, the lack of statistical analysis in condition (3) and the limited sample of subjects (from seven to three in some cases) diminish the value of several of the authors' conclusions, particularly those concerning energy expenditure on the mountain slopes.

187

Wokoun, William, Vigilance with Background Music, Aberdeen Proving Ground, Md., U.S. Army Human Engineering Labs., Tech. Memo. 16–63, AD #433,624 (1963).

Abstract:

The effect of background music upon performance on a vigilance test was studied. "Vigilance" was defined as "watchkeeping performance in an unstimulating environment." The 14 subjects were males between the ages of 18 and 35 employed at Aberdeen Proving Ground or Edgewood Arsenal. They were presented with 8 light stimuli of 3 different colors during a one-hour test. The subjects responded by pressing the appropriate one of 3 keys, and response times were measured. The independent variable was music (a specially programmed Muzak tape recording with music similar to that ordinarily played in offices and industry) vs. continuous noise (a fan of similar loudness). The subjects also took a Thurstone-type attitude scale about the music they had heard.

The performance of subjects who worked while hearing noise did not change significantly during the hour. However, the subjects who heard background music responded significantly better, i.e., faster, during the latter two-thirds of the hour than they had at first. Also, the music group performed significantly better in the middle third of the hour than during the last third. Other tests, comparing the groups with each other, rather than with themselves, did not demonstrate significant differences. Surprisingly, the median attitude score was somewhat lower in the music group than in the noise group.

The methodology in this study was well and comprehensively reported, and adequate statistical treatment was given to the data. However, the author's manipulation of the results must be kept in mind. In the original experiment, each of the two groups of subjects worked both with music and with noise, each group starting with a different condition. But the author could find no significant relationships until he excluded the second test situation entirely and worked only with data from the first testing hour for each group. This exclusion was justified by the author as an attempt to eliminate uneven transfer effects and extraneous progressive responses (e.g., due to fatigue or learning). A further reason was the fact that several subjects correctly guessed the independent variable when they found, at the beginning of their second test, that music had been added to or subtracted from the experimental situation, and this knowledge could have influenced their response.

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Young, H. H., The relationship between heart rate and the intensity of work for selected tasks, The Journal of Industrial Engineering 7 (6), 300–303 (1956).

Abstract:

Two studies were conducted to find the correlation between heart rate, following a timed interval of work, and the pace of the operator during the work cycle—for particular job requirements. The variables affecting heart rate—temperature, humidity, impervious clothing, sex, age, training, emotional state, and physical condition—were controlled for or minimized as much as possible.

In the first study, 14 male graduate students between the ages of 23 and 31 served as operators in pumping the handle of a small hydraulic hand pump at prescribed paces of 80, 100, and 120 double pump strokes per minute. The order in which the paces were presented was randomized over the 14 operators. Work periods lasted two minutes, with a ten-minute rest period before the first pace was tried and between each work cycle at different paces. The heart rate was counted with a stethoscope at the end of each two-minute work period and at one, two, and three minutes thereafter, and the time in seconds for 30 beats was measured with an electric stop-watch. It was found that as the pace increased, the number of heartbeats per minute increased for all of the operators at the reading taken immediately after work, but in some cases the heart rate recovery curves crossed at two to three minutes after cessation of work. An analysis of variance of the means of the heart rates taken immediately after work were significantly different beyond the 0.05 level for each of the three paces. Correlation coefficients between pace and heart rate ranged from 0.889 to 0.999 for the 14 operators immediately following work, and from 0.363 to 0.999 for one minute after work.

In the second study, 16 graduate students performed four tasks: (1) moving a push-pull handle horizontally against a resistance at three different paces (90, 110, and 130 double strokes per minute), (2) walking on a level floor at 110 steps per minute, (3) climbing stairs at 130 steps per minute, and (4) lifting a 30-pound load from the floor, carrying it for 25 feet at a pace of 90 steps per minute, and putting it back on the floor. Work and rest periods and method of heart recovery rate determination were the same as in the first study. Time of day was varied, with eight of the subjects working at 10:00 A.M. and the other eight at 2:00 P.M. The data were subjected to analysis of variance using a three-way classification of data. The task factor had an effect on the measured heart rates significant beyond 0.01. The effects of the particular operator and of the time of day were each significant at 0.01, indicating that these two factors were not independent of each other in affecting operator heart rates. It appeared, then, that the intensity of work on a task can be predicted from direct measurements of heart rate following work.

This is a good study, though it might be wished that the author had presented his heart rate data in standard fashion (beats per minute rather than time per 30 beats) to facilitate comparison with results obtained by Brouha and others.

189

Zapp, John A., Jr., Physiological evaluation of the chemical environment, Physiology in Industry, Chapter 2–3, pp. 69–82 (1960).

Abstract:

In industries involving exposure to chemicals, the industrial physician is charged with preventing workers from being injured by their chemical environment. This includes not only the obviously dangerously toxic agents, but also exposure at levels which produce only a *minimal bodily injury*—often showing up only as a small physiological change in the worker. If the physician cannot measure a single individual long enough, he is justified in using established group averages and variations as a baseline for determining whether an individual or a certain group of workers is abnormal. Observations of the blood pressure response of dogs and the urinary response in rats upon exposure to chlorotrifluoroethylene are reported. In the dogs, changes in blood pressure, as well as hematological changes, occurred at an exposure level unproductive of any clinical signs of toxicity. The rats showed no clinical signs of toxicity, but severe tubular necrosis was found on sacrifice—continued exposure at high levels resulted in death in some subjects (both dogs and rats).

Two groups of workers, one exposed to nitroglycerine, finished a work cycle with the same average heart rate measured 30 s to 1 minute after sitting. On successive readings during the recovery period the nonexposed group showed a typical recovery, while the exposed men maintained a comparatively fast rate for the whole 15-minute period. This reaction disappears shortly after the men were removed from the exposure situation, indicating that the abnormality is temporary and completely reversible. In this case, change in an easily observable physiological function permits an early diagnosis of exposure which can be followed promptly by adequate correction or protection. The author cautions in closing that not all physiological changes are presumptively harmful. Some may merely represent the organism's normal and completely adequate response to an environmental change.

190

Zolina, Z. M., et al., Physiological evaluation of the work and rest schedule in the 7-hour work day on an assembly line, Gigiena Truda i Professionalnye Zabolevaniya 7, 28–33 (1963).

Abstract:

Following adoption of a 7-hour working day at industrial enterprises a special physiological investigation at a conveyer assembly line of wrist-watches "Zvezda" was instituted. It dem-

onstrated that the sensation of fatigue (determined dynamically throughout the work day by shifts in the time spent for the performance of any particular operation, excitability and lability of the motor and visual analyzors, steadiness of attention) in female-workers diminished considerably, as against the data shown by inquiries effected previously during the 8-hour work day schedule. Of prime importance for a sustained high performance capacity of female watch assembly operators viewed dynamically throughout the day, is the greater length of free time ("micro-pauses" comprising 15–20 percent of the total work day), obtained at the expense of reduced operation time (by 12–15 percent) as against the comparable data for 8-hour work day schedule).

In a certain measure the rise of labor productivity was attributable to a change-over to a different operational procedure of picking manufactured articles up from the conveyer belt (chiefly by facilitating the work of eyes).

A good study. Results are provided in the form of charts as well as discussed in the body of the paper. (Author's Summary.)

VIII. Indices

A. Author Index to the Abstracts

*Numbers refer to abstract numbers.

B. Subject Index to Abstracts

way 1946; Brouha 1960c, d, e, f; Brouha and Mazfield 1962; Christensen 1953; Dill 1961; Domanski et al., 1951; Ekey and Hall 1961; Flying Personnel Research Committee 1965; Geldreich 1953; Glassner and Peters 1959; Hanson 1961; Henschel 1967; Mack and Dixon 1955; Müller and Rech 1955; Nagle et al., 1963; Patterson et al., 1964; Plattner 1967; Ricci et al., 1965; Schane and Slinde 1967; Shannon 1966; Sharkey et al., 1966. Strydom and Wyndham 1963; Vetter and Horvath 1961; Vogel et al., 1967; Winsmann and Daniels 1956; Young 1956; Zapp 1960.

Heart Sound—Ekey and Hall 1961.

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Ionization—Chiles, et al., 1960; DeVries and Klafs 1965.

Mental Tasks—Adams and Chiles, 1960, 1961; Baker and Ware 1966; Bitterman and Soloway 1946; Blake and Proctor 1965; Botwinick and Shock 1952; Brown 1962; Chiles 1955, 1958; Drew 1960; Geldreich 1953; Glassner and Peters 1959; Kahneman et al, 1967; Laporte 1966; Lybrand 1952; Ward et al., 1965; Wendt 1953; Weston 1953; Williams et al.. 1958.

Metabolic Rate—Christensen 1953; Daniels et al., 1953; Du Bois 1960; Goldman 1965; Winsmann et al., 1953.

Monitoring—see "vigilance".

Monotony and Boredom—Baker and Ware 1966; Colquhoun 1959; Kennedy and Travis 1947; Pierson 1963; Pierson and Lockhart 1964; Wendt 1953.

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"On-the-Job" Studies—Austin et al., 1967; Brouha 1953, 1960a-f; Brown 1962; Bullen 1956; Christensen 1953; Davenport 1955; Davis and Taylor 1954; Domanski 1953; DuBois 1960; Fischer et al., 1961; Flying Personnel Research Committee 1965; Grandjean, E. 1959; Grandjean and Jaun 1960; Green 1960; Griffith et al., 1950; Hauty and Adams 1965a, b; Jackson 1956; Kikolov 1960; Laporte 1966; Lundervold 1957; Pace et al., nd; Platt 1964; Plattner 1967; Ruff et al., 1966; Shepherd and Walker 1957; Smith 1961; Vincent 1965.

Opthalmographic Tests—Brozek and Simonson 1952.

Oxygen Consumption and Debt—Astrand and Saltin 1961; Balke 1954a, b; Brouha 1960c d; Brouha and Maxfield 1962; Christensen 1953; Consolazio et al., 1963; Dill 1961; DuBois 1960; Goldman 1965; Hansen et al., 1967; Henschel et al., 1967; Kreider et al., 1961; Nagle, et al., 1963; Noltie 1953; Ricci et al., 1965; Sharkey et al., 1966; Walk and Sasaki 1965; Winsmann and Daniels 1956; Winsmann et al., 1953.

Performance Decrement—Blake and Proctor 1965; Botwinick and Shock 1952; Geldreich 1953; Hanes and Flippo; Lybrand 1952; McGehee et al., 1953; Pierson 1963; Pierson and Lockhart 1964; Whittenburg 1953.

Performance Enhancement—Blake and Proctor 1965; Byck and Hearst 1962; Lybrand 1952; McGehee et al., 1953; Payne and Hauty 1953, 1955.

Perspiration, sweat loss—Adams et al., 1963; Baker 1958a; Balke 1954a; Brouha, 1960e; Brouha and Maxfield 1962; Carlson 1961; Hanson 1961; Hauty and Adams 1965b; Randall et al., 1953; Strydom and Wyndham 1963; Winsmann, et al., 1953.

Physical Exercise Tasks—See also "Bicycle", "Step Test", "Walking"—Astrand and Saltin 1961; Auxter 1966; Balke 1954a; Bilodeau 1954; Brouha 1960f; Brouha and Maxfield 1962; Consolazio et al., 1963; DeVries and Klafs 1965; Dill 1961; Domanski et al., 1951; Ekey and Hall 1961; Evans 1961, 1962; Goldman 1965; Hanson 1961; Holmgren and Harker 1966; Hussman 1952; Knowlton et al., 1951; Kreider et al., 1961; Lemkuhl and Imig 1961; Mack and Dixon 1955; Matoush et al., 1963; Miller and Mason 1964; Nagle et al., 1963; Nagle et al., 1966; Noltie 1953; Patterson, et al., 1964; Rasch and Wilson 1964; Redfearn, et al., 1957; Ricci, et al. 1965; Schwab and Brazier 1958; Shannon 1966; Sharkey et al., 1966; Sheperd and Walker 1957; Strydom and Wyndham 1963; Todd and Allen 1960; Vetter and Horvath 1961; Walk and Sasaki 1965; Winsmann and Daniels 1956; Winsmann et al., 1953; Young, H. H. 1956.

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Pressure—Tiller 1961.

Psychiatric Analysis—Colquhoun 1959; Hanes and Flippo 1963; Hussman 1952; Schwab and Brazier 1958; Shands and Finesinger 1949; Spaulding 1964; Taylor 1961; Wilbur 1953.

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Respiration—See also "Oxygen Consumption"—Astrand and Saltin 1961; Ayoub and Manuel 1966; Balke 1954a; Carlson 1961; Consolazio et al., 1963; Flying Personnel Research Committee 1965; Geldreich 1953; Glassner and Peters 1959; Goldman 1965; Hauty and Adams 1965b; Henschel et al., 1967; Jhurkov and Zaharianz 1960; Kreider et al., 1961; McDonald et al., 1963; Nagle et al., 1966; Plattner 1967; Sharkey et al., 1966; Simons et al., 1965.

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Sociological Factors—Bucklow 1966; Green 1960; Katz 1965; Shands and Finesinger 1949.

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