AD-755 081

PERFORMANCE AND BIODYNAMIC STRESS-INFLUENCE OF INTERACTING STRESSES ON PERFORMANCE

Advisory Group for Aerospace Research and Development
Paris, France

November 1972

AD755081

AGARD-CP-101

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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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on

Performance and Biodynamic Stress -Influence of Interacting Stresses on Performance

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AGARD Conference Proceedings No.101

PERFORMANCE AND BIODYNAMIC STRESS – INFLUENCE OF INTERACTING STRESSES ON PERFORMANCE

Papers presented at the AGARD Aerospace Medical Panel Specialist Meeting
held in Brussels, Belgium on 2 June 1972

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Published November 1972

613.69:159.944

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PREFACE

The program documented in these Proceedings originated from suggestions by two of the Committees within the AGARD Aerospace Medical Panel. "Permance and Biodynamic Stress," was the topic proposed by the Biodynamics Committee in the early stages. The Behavioral Sciences Committee simultaneously proposed a session on the "Influence of Interacting Stresses on Performance."

I would like to acknowledge your Co-chairmen, Squadron Leader David Glaister from IAM, Farnborough, who has been the co-representative of the Biodynamics Panel of which I am a Member and Dr. Walter Grether from the Aerospace Medical Research Laboratory at Wright-Patterson AFB, who was the major contributor in organizing the program from the Behavioral Sciences Committee.

The general topic of interacting stresses is, as I know you are all aware, one which can be almost as broad as one would care to make it if one considers all of the possible stressors that can influence the crew member acting either sequentially or in combination with one another.

To focus our discussion on some of the more pressing operational problems and to facilitate the organization of our thinking about this complex R&D area, some arbitrary divisions of the problem are proposed:

A. Transient Stressors

1. Escape and Impact: Sequential or simultaneous high magnitude (mainly biodynamic) environments; the major R&D objectives are to provide capability to survive without injury under emergency conditions. These topics were discussed in detail by the Panel in 1971.*

2. Tactical Missions (3-4 hours or less): (a) Environmental extremes to which the crew is exposed prior to takeoff such as heat and humidity, (b) helicopter and VTOL operational environments including vibration and noise, (c) low altitude high speed flight involving terrain following acceleration and turbulence induced vibration, (d) combat maneuvering acceleration coupled with antecedent breathing of 100% oxygen with attendant interactions of these environments on the aircrewman's physiological response, and (e) effects of task loading and repeated missions. These are only examples of the kinds of interactions and the kinds of operational environments that are of concern and which are interrelated to the workload stress that is associated with this kind of situation. In these transient or relatively short duration flights, the general concerns are (a) to define effects of the complex operational environment on the crewman's ability to perform his flight task, (b) to determine the interaction of personal equipment, of protective systems as well as environmental control systems in determining certain operational ground rules such as the permissible frequency of multiple flights per day and the like, and (c) to improve new systems design criteria for the above goals.

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*AGARD Conference Proceedings No. 88, Linear Acceleration of Impact Type, Published December 1971.

B. Long Duration Stressors (durations greater than 3-4 hours): Combinations of environmental stressors are present but tend to occur generally at low intensity, with perhaps intermittent (sometimes unexpected) brief periods of more intense exposure. In the bomber and transport aircraft situation, relatively low magnitude environmental stressors (acting for long durations) interact with such factors as workload, duration of flight, time zone shifts, etc. The practical outputs from R&D in this area are definitions of trade-offs involved in determining crew to aircraft ratios and work/rest cycles and providing better man/machine interface for these long duration flights.

In soliciting papers for this Conference, a series of topical areas (around which the conclusions of the Conference are organized) was proposed which we hoped would focus the formal presentations and, in particular, the discussion towards practical conclusions. Among these are (a) concise statements, in terms useful to operational planners and systems designers, of what we know today about the effects of multiple stressors on crew performance and survivability; (b) definition of improved methods for producing adequate information on combined stressor effects from both operational and laboratory simulations to facilitate planning these very difficult experiments; (c) consideration of the interactions of personal equipment designed for protection against or enhancement of performance during exposure to a single flight stressor as these various equipments are used together. The objective here is to emphasize the importance of optimizing these combinations of equipment by recognizing that, for instance, protection against one environment (flak suit) may degrade protection in another environment which occurs concurrently (heat, escape); (d) definition of concepts and considerations which provide for improved utilization of aircrews in terms of scheduling, crew ratios, etc.

Our success in addressing each of these topics was not uniform. The presentations and proceedings by their inherent nature obviously do not constitute a stepwise logical and complete review of the literature. However, from the standpoint of the operational planner and systems designer, the results of this meeting should clearly show the relative complexity of this area and depict an excellent representative sample of the current thinking and state of knowledge.

CONTENTS

GENERAL DISCUSSION

TECHNICAL EVALUATION

As indicated in the Preface, the original call for papers for this Conference was organized around a series of topical areas designed to cover the most important selected aspects of the total problem of combined stress effects from the standpoint of military applications. As expected, coverage of these topics has not been uniform; however, at least some coverage has been provided in almost all major areas. Accordingly, these topical areas have been used in the following lines to briefly evaluate the Conference.

Definition of the Operational Environment

Either measurement or prediction of the biologically significant aspects of the operational environment is an obvious first step towards acceptable simulation and study of crew effects. The flight test situation is often the only way the operational environment can be adequately simulated, particularly when combined stressors are involved. Squadron Leader Trumper described the development of a dedicated high performance aeronautical test bed for obtaining precise measurements of the environment and of the crew's ability to perform in the environment. Many previous attempts to gather significant performance data under operational settings have been limited by the necessity of collecting data on a non-interference basis during flights with primary missions dedicated to other goals.

Interactions of Operational Flight Stressors

Dr. Grether's paper on combined effects of heat, noise and vibration reported no additive interactions of stress effects at the relatively low levels of individual stressors employed. While vibration alone produced performance decrement, neither heat nor noise at the intensities studied produced individual effects. As pointed out by Dr. Grether in the general discussion, one might expect a different effect if the levels of individual stressors were increased. Mr.Sommer's paper on effects of noise and vibration on psychomotor performance reports tentative conclusions supporting an additive effect of these two stressors on a short term memory/subtraction task and questionable effects of the combination on vertical and horizontal tracking tasks. Both speakers strongly state the difficulty in experimental procedure and design which is well summarized in Dr. Grether's general remarks. It was apparent from the discussion that we have only begun the tedious task of deriving operationally significant answers from laboratory simulations of interacting flight stressors.

Current Exposure and Performance Criteria

Mr. Allen pointed out some of the deficiencies associated with some of the earlier vibration data and the need for more specific measurements of the environment associated with the experimental situation. There was no other formal presentation on this subject.

As indicated in the Preface an important consideration of the interaction of combined stressors, as regards the adequacy of exposure and performance criteria now used for individual stressors, involves the effects of various kinds of protective devices for one environmental extreme on the physiologic cost of using the device (positive or negative) when exposed to another facet of the combined environment. Since this important area was not discussed in any detail during the Conference, your Editor is taking the liberty of including the following table which illustrates, at least qualitatively, the nature of the interactions of potential concern.

PROTECTION SYSTEM INTERACTIONS
WITH COMBINED STRESS ENVIRONMENT

	comfort	crash protection	ejection	heat, cold	altitude	radiation	projectiles	vibration
Pressure Suit	-	0	-	-	+	0	0	-
G Suit	-	0	0	-	+	0	0	0
Flack Vest	-	+	-	-	0	+	+	0
Oxygen Equipment	-	-	+	0	+	0	-	0
Thermal Suit	-	0	+	+	0	0	0	+
Restraint	-	+	+	-	0	0	0	+

+ enhanced protection

- degraded protection

0 no effect

Physiological Basis for Performance Decrement

Squadron Leader Glaister's paper described the influence of emotional factors on the response to G_z and some of the physiological mechanisms involved in the interaction. Dr. Hartman's paper dealt with the concept of defining the cost of transport missions by measurement of associated metabolic changes. Dr. Auffret's paper further described the physiological modifications associated with long duration flights. Dr. Meyer-Delius described the interaction of workload and climate. Group Captain Howard drew the analogy between money in a bank account and physiologic reserve, pointing out that most measures define only what's been withdrawn and do not reveal the balance or reserve remaining. Colonel Lecocq's paper dealing with provocative stress testing offers hope of providing this measure of reserve as well as providing the common measure of stress cost across various kinds of flight missions.

Performance Measurement Methodology

Captain Roger's paper on the human operator model describes an input-output closed loop performance measurement methodology which has achieved initial success in describing the crewman's ability to perform an operationally oriented task. The method considers the dynamics of the system being controlled, the man-machine interface and the effect of simulated flight environments. It does not necessarily require knowledge of underlying physiologic basis of performance decrement to produce operationally meaningful answers although the method is used to suggest mechanisms of action of effects of performance decrement. Dr. Hoffelt proposed administration of questionnaires to bring out various psychological aspects of the total response to flight environments. Lt Gibson discussed training procedures which not only bear on training problems per se but on some important aspects of experimental design on the complicated area of multiple stress studies.

Performance Enhancement:

Captain Shubrooks reported on various alternatives for increasing G_z tolerance such as modifications of the Valsalva maneuver, redesign of G valves and use of positive pressure breathing.

Conclusions

The papers and discussion in this Conference clearly show the fact that flight stressors occur in sequence or in combination under operational conditions in such a way that, under at least some conditions, significant interactions between stressors act to influence crew performance. The nature of these interactions has not generally been well established and in some cases has only been qualitatively evaluated under operational flight conditions. Simulator limitations have been a major deterrent to our ability to perform more quantitative studies; however, significant new progress in simulator technology and methods for using this technology are emerging rapidly. In the biomechanics area, there are now evolving reasonably complete models which embody unifying concepts of force-tissue deformation that explain the body's response to vibration, impact, blast and rapid decompression. It seems likely that major progress in understanding the interactions of more diverse stressors, as they affect man's ability to perform flight duties, will be in considerable measure based on our ability to develop more general unifying concepts and principles such as are exemplified in the biomechanics area.

EARLY THOUGHTS ON COMPOUND STRAINS *

by

Geoff Allen
Head of Environmental Effects Section,
Human Engineering Division, EP Dept.,
Royal Aircraft Establishment, Farnborough, Hants

SUMMARY

Jargon on the subject is briefly discussed, and it is reasoned that the term 'compound strains' may frequently be more appropriate than 'combined stresses'.

It is postulated that we should first learn how to deal with the effects of so-called single stresses before plunging too deeply into the even-more complex problems of compound stresses. As an example, the present confusion between the results of investigations of body vibration effects is analyzed, and the resulting lessons are related to investigations of compound strains. In particular, the need for national and international consistency in the conduct and reporting of investigations is highlighted, and some proposals, based on the approach by a UK informal working group, are put forward.

Two compound strain problems of immediate and widespread importance, on which there is an urgent need to increase the present scanty information, are cited. The first is the effects of other mental and physical stresses on the signal to noise ratios required for communication; the second, the biodynamics of vibratory motion sickness, particularly the interaction with other loads such as vision, heat and odours.

LIST OF SYMBOLS (for vibration of the human machine)

V = vibration inputs
Ph = physiology of machine
G = geometry of machine and interfaces
E = other environmental inputs
Ac = activity (the human machine is rarely dormant unless in a cataleptic trance)
Ps = psychological influences
Ad = adaptability (the machine in many circumstances can adapt itself physically or 'psychologically' to vibration or can adjust the vibration levels or eventually 'escape')
T = 'time' (duration of exposure, age of machine, time of day)

INTRODUCTION

Most of the author's and his colleagues' efforts on the effects of environmental stresses and strains on people have so far been absorbed by the unsolved problems of quantifying so-called single stress situations, particularly for noise and vibration. The purpose of this paper is firstly to consider and relate some of this experience to the more complex problems of compound strains, and secondly to highlight two such situations, which in the author's view are of widespread and immediate practical importance and require more exploration.

JARGON

Right at the start newcomers to this field are faced with the usual problem of jargon. Wilkinson[1] has already suggested that 'stress', although perhaps less accurate, is less clumsy, and therefore to be preferred to 'stressors'. In any case, to the engineer and physicist at least[2], 'stress' is a loading per unit area and the result, that is the deformation or disturbance it produces, is a 'strain'. This serves to remind us that for different people, as for different materials, identical stresses can produce vastly different strains. Also in combined stress work it is the dependent variables - the strains which are our real problems rather than the loads or stresses *per se*. Greater use of the term 'strain' would therefore seem to be worth encouraging. Similarly, 'combined stress' is the phrase perhaps most commonly used to describe this work, but 'combined'[3] infers a uniting, a coalescence, an affinity between the stresses. This may or may not be so in practice and the less specific 'compound' is in the author's view therefore to be preferred.

PROBLEMS OF SINGLE STRESS INVESTIGATIONS

This section aims to summarise some of the fundamental difficulties which face those seeking to explore human reaction to an environmental load. Mechanical vibration is selected as a particular example, this subject having been studied in depth by the author and his colleagues. Vibration provides what is perhaps the most complex, most pervasive of the common environmental stresses, and is a specific case from which wider generalisations may be drawn which in turn may be applied in principle to compound stress and strain situations.

The problems of establishing human reaction to vibration have been explored in greater depth in another paper[4]. In this paper extracts and some additional material are given, firstly to illustrate the confusion, secondly to analyze some of the reasons for it, and finally to suggest ways and means of

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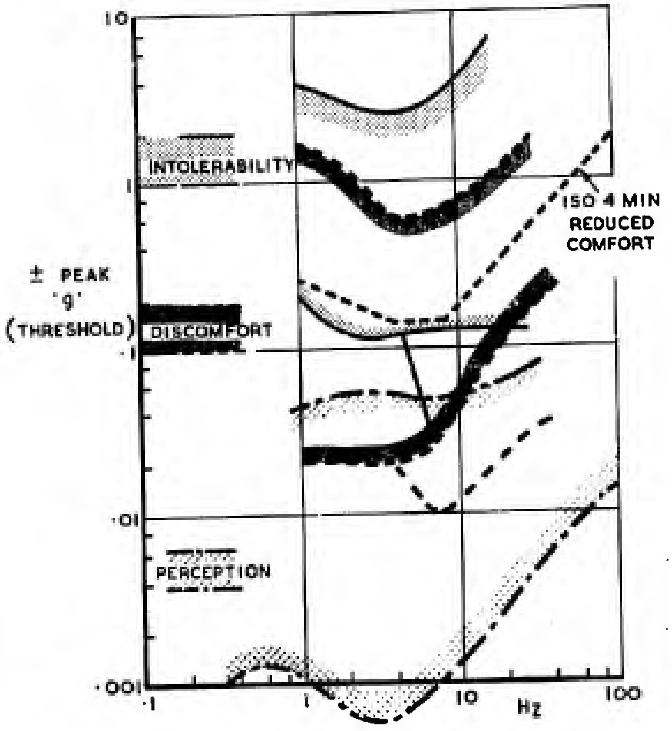
improving the situation. The confusion is graphically illustrated in Fig.1, which has been derived from information in an admirable review by Hanes[5] and sums up the results of some 18 'classical' laboratory investigations on the subjective reaction of sitting and standing persons to vertical 'sinusoidal' vibration. Each of the 3 bands in this graph encloses the spread of mean results of investigations of what can be broadly termed the onset or threshold of 'intolerability', 'discomfort' and 'perception'. One is immediately confounded, firstly by the enormous spread which ranges in 'g' from up to 100 to 1 for perception, 50 to 1 for discomfort and 80 to 1 for intolerability, and secondly by the overlaps - in one region around 8 Hz and 0.03 g apparently an intolerable vibration is imperceptible! Although as discussed later in this paper some of the scatter may be attributable to subject variability, most of the results in Fig.1 are based on means for subject populations, admittedly varying between as little as one but as many as 100, and with an average of about 18 subjects per experiment.

Another major area of uncertainty is the relevance of laboratory work, which provides the bulk of the evidence, to real life situations. In Fig.2 the band of discomfort thresholds from 13 laboratory investigations, previously plotted in Fig.1, is compared with a band of 'unacceptable' vibration levels obtained from the mean results of 5 field investigations summarised by Bryce[6]. Although the investigations are not directly comparable, the graphs suggests that vibration which is deemed only 'uncomfortable' in the laboratory, may well prove 'unacceptable' in real life - unacceptable presumably for psychological rather than physical reasons.

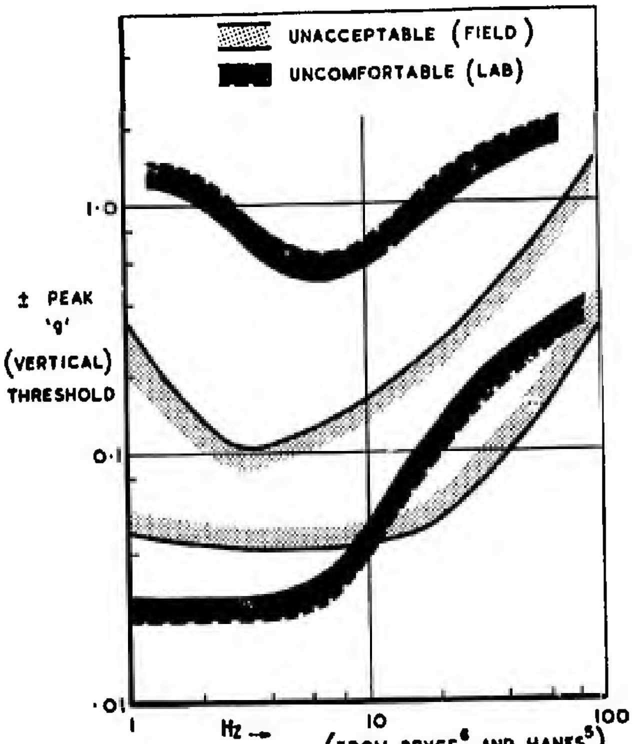
The previous analysis has illustrated the wide differences which exist between the results of investigations when mean subject populations results are compared. These differences tend to increase when inter-subject variations are considered. Typical wide subject scatter in 'definitely perceptible' and 'alarming' reaction levels[7] is illustrated in Fig.3 and in visual acuity[8] in Fig.4.

Careful analysis of the problem, particularly of the many variables involved should at least indicate some of the reasons for this diffuse, confusing and often apparently contradictory information on human reaction to vibration. Fig.5 is a pictorial illustration of the problem of measuring the response of the human machine, this most complex of all machines, to mechanical vibration as seen through the eyes of a Vibration Test Engineer. The machine comprises a closely integrated, interacting collection of structural, pneumatic, hydraulic, electrical, chemical and thermodynamic systems to name just a few, controlled by a unique creative computer, employing highly sensitive optical and acoustic systems. The characteristics of most of these systems vary from time to time, sometimes in a random, sometimes in a periodic fashion, and there is a very wide variation between the characteristics of apparently similar machines. The machine is capable of performing an infinite variety of operations and in the example illustrated is engaged on a control task



(AFTER HANES[5])

Fig.1 Subjective reaction to vertical sinusoidal vibration



(FROM BRYCE[6] AND HANES[5])

Fig.2 Reaction to vibration: field v. lab. evidence improving the situation. The confusion is graphically illustrated in Fig.1, which has been derived from information in an admirable review by Hanes[5] and sums up the results of some 18 'classical' laboratory investigations on the subjective reaction of sitting and standing persons to vertical 'sinusoidal' vibration. Each of the 3 bands in this graph encloses the spread of mean results of investigations of what can be broadly termed the onset or threshold of 'intolerability', 'discomfort' and 'perception'. One is immediately confounded, firstly by the enormous spread which ranges in 'g' from up to 100 to 1 for perception, 50 to 1 for discomfort and 80 to 1 for intolerability, and secondly by the overlaps - in one region around 8 Hz and 0.03 g apparently an intolerable vibration is imperceptible! Although as discussed later in this paper some of the scatter may be attributable to subject variability, most of the results in Fig.1 are based on means for subject populations, admittedly varying between as little as one but as many as 100, and with an average of about 18 subjects per experiment.

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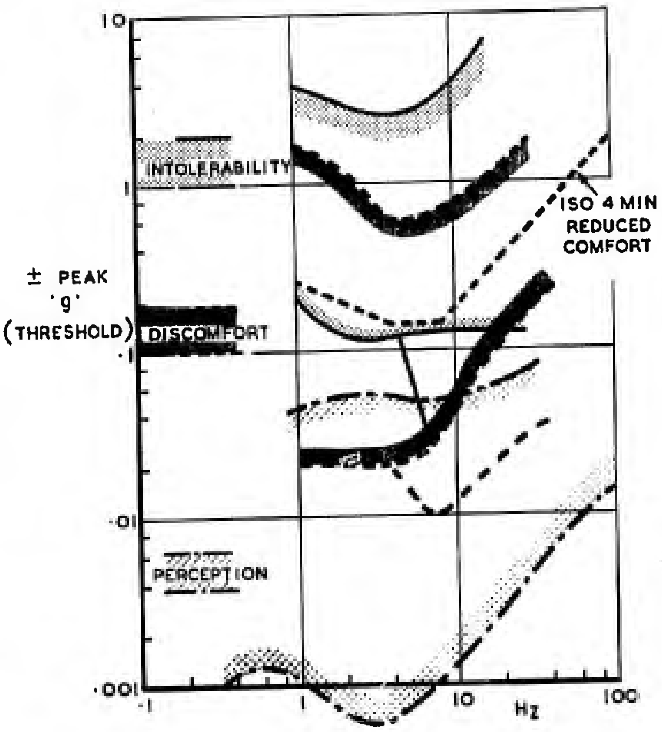
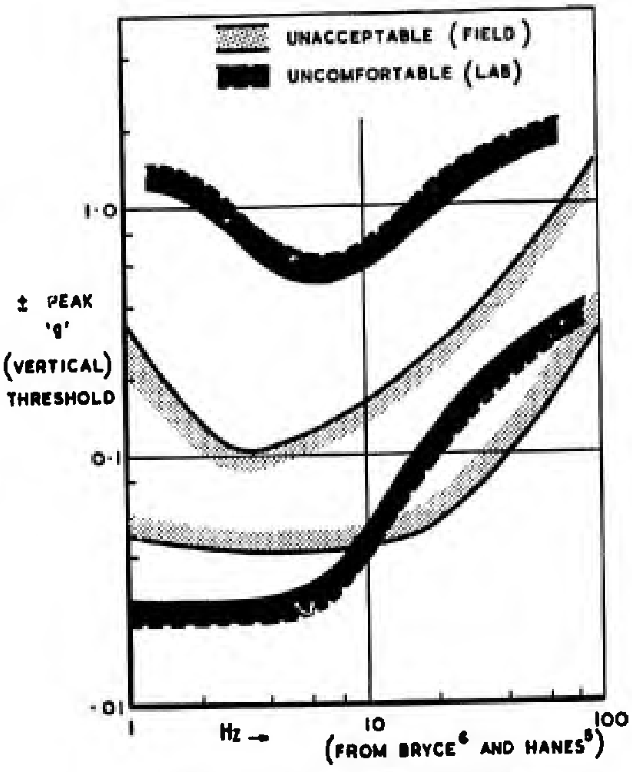


(AFTER HANES[5])

Fig.1 Subjective reaction to vertical sinusoidal vibration



(FROM BRYCE[6] AND HANES[5])

Fig.2 Reaction to vibration: field v. lab. evidence

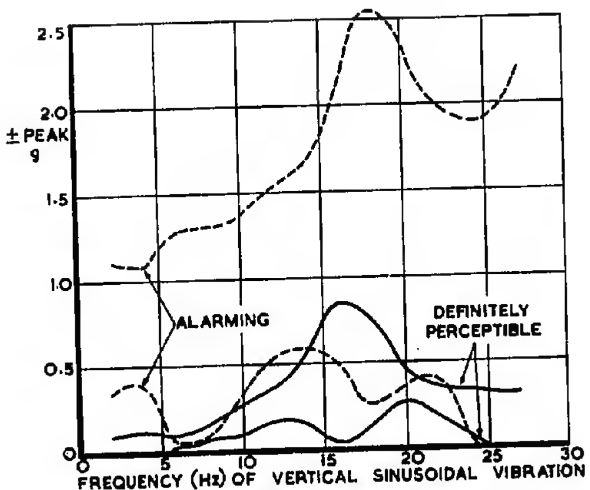


Fig.3 Approximately ±2σ range for judgements of 'definitely perceptible' and 'alarming' (after Parks[7] and Hanes[5])

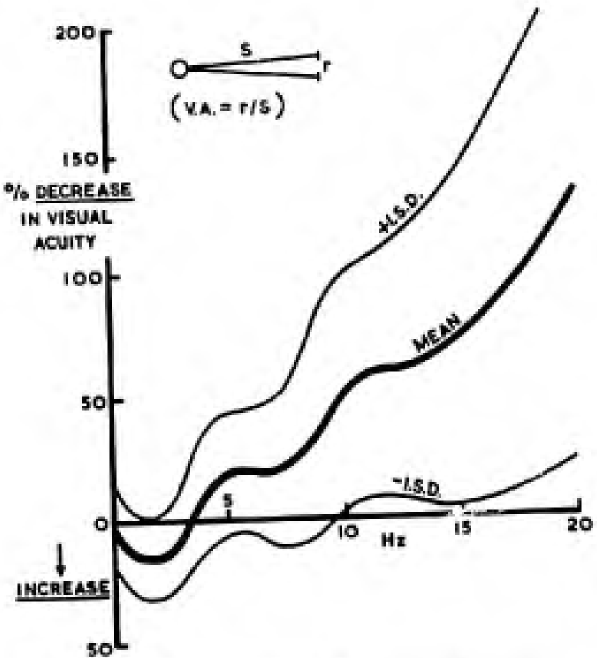


Fig.4 Subject variation in effects of vertical vibration on visual acuity (after Lange and Coermann[8])

involving particularly its optical but also its structural and other systems. The vibration varies in amplitude, direction, frequency and phase at the several inputs to the machine. Furthermore, the optical target and the control handle are also vibrating differently. The test is made much more difficult by other properties of the machine. Firstly, its response and performance are sensitive to other physical environmental inputs (top right hand corner of diagram) in particular to sound, light and heat; for example, a change in ambient temperature of only a few degrees will significantly alter its thermodynamic control, and some of the other inputs, particularly sound, are likely to interact with vibration in a complex manner. Secondly, as previously stated, the machine characteristics and performance are considerably affected by the physical state of its components. These fluctuate widely with 'health', 'biorhythms'[9,10] age and time employed on the task. Last but by no means least, the behaviour of the machine is susceptible to strange influences which have no physical analogy but which are termed 'psychological'. These influences directly affect the creative computer control centre and through this most of the other parts of the other machine. The machine is extremely susceptible to these influences which include long and short term previous experiences, motivation, etc but it also has a considerable ability to adjust or adapt itself to various vibration conditions. Exit Vibration Engineer, in complete confusion!

This pictorial representation of the immense problem of vibration of the human machine can be converted into at least a qualitative mathematical equation. The equation of human reaction to vibration (HRV) can be expressed as:

$$HRV = f\,[(V,Ph,G,E),\ Ac,\ (Ps,Ad),\ T]$$

This equation is reiterated and the major variables are expanded into subvariables in Fig.6. In this figure the items which are underlined and the groups which have a thick frame indicate those which have received inadequate, sometimes virtually no attention in laboratory or field investigations. Also, remember that the vast bulk of investigations have been in the laboratory where little attempt has been made, or is in fact possible, to cover the psychological or adaptability variables, so that, as previously stated, many such investigations are of doubtful relevance to real life situations.

How much of this equation can be quantified? The author suggests that we can fill in with any confidence only a very small fraction of the total variables involved. Several analogues, empirical equations and scales of human reaction have been derived, for example, by Coermann[11], von Gierke[12], Sperling and Betzhold[13] and Dieckmann[14] but these cover only a fraction of the variables in the HRV equation and any wider applicability to other subject populations, other laboratory or real life conditions is very dubious.

What lessons can be drawn from the analysis above?

Firstly, the situation illustrated in Fig.5 and the equation derived, indicate the great difficulties of establishing human reaction to vibration, and hence the need to employ high standards of investigation. Unfortunately, as acknowledged by authorities such as Guignard[15] and Harris and Shoenberger[16], this vital need has frequently not been met. Another paper would be required to discuss this subject in depth but essentially, standards of planning, executing and particularly reporting, have with few exceptions, been most inadequate and in the author's view are one of the main causes of the present confusion. Many of these criticisms which include for example no measurement of the vibration input into the body, no definition of the vibration acceleration waveform, inadequate control tests, are implicit in Fig.6 and can be levelled at many of the 'classical' investigations which are the foundations on which the present structure of information on reaction to vibration is based. In the UK attempts are being made to improve the situation by putting forward recommendations for vibration investigation methodology and reporting[17]. It is felt that some agreement on techniques and reporting would be invaluable on an International as well as a National basis.

Secondly, we should encourage more field, particularly real life investigations, as frequently only these can provide realistic evidence on human reaction to vibration. In the UK this work is being encouraged at Universities and elsewhere.

THE APPROACH TO COMPOUND STRAIN INVESTIGATIONS

Obviously the inclusion of more than one strain into the investigation complicates what will already generally be a complex situation for each individual strain. This calls for an exceptionally rigorous, disciplined approach to the planning, executing and reporting of investigations. In this paper, drawing upon this experience particularly obtained in vibration and noise work, the author can do no more than outline what are, in his opinion, some of the vital and fundamental aspects of methodology and reporting which must be considered if we are ever to obtain information which may be correlated and applied with some confidence to real life situations. The following suggestions are built round a typical experimental plan given in Fig.7 and to some extent follow the lines being followed by an informal UK working group on experimental methods for body vibration investigations.

a Experimental objective

Careful consideration and definition of the objects of the investigation particularly its relevance to real life situations will generally be the first essential step towards a well-planned, worthwhile investigation.

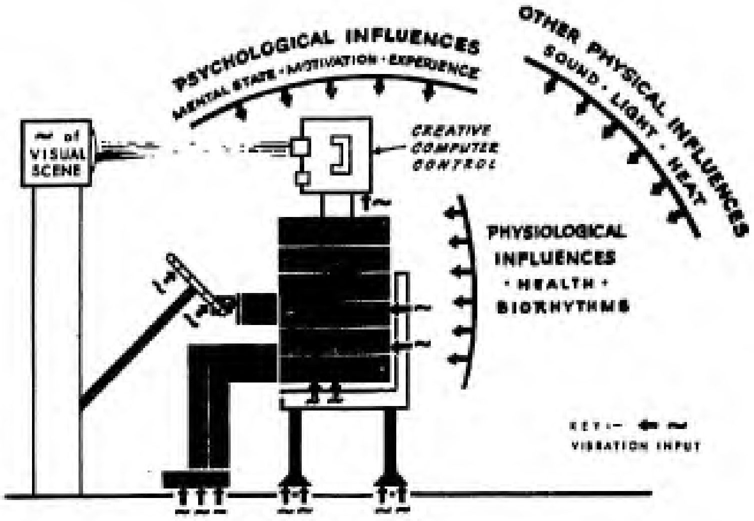


Fig.5 Vibration of the human machine

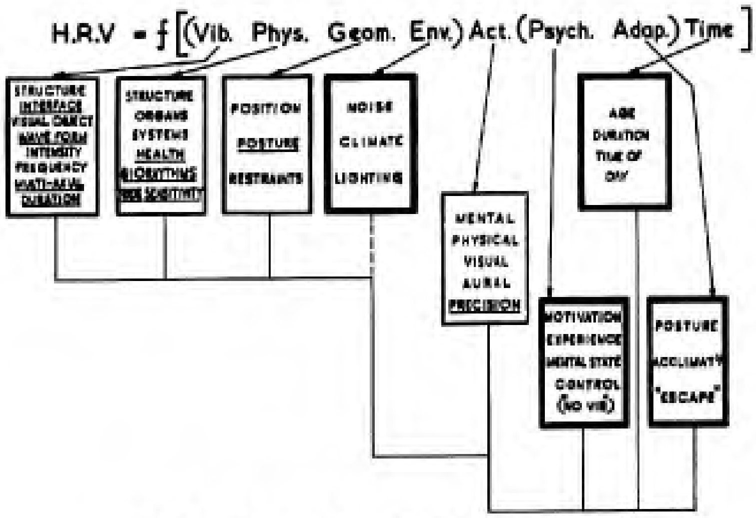


Fig.6 The equation of human reaction to vibration

b Apparatus and method of use (subject inputs)

Although details will vary for different experiments, there will in general be 5 elements to be controlled and described under this heading:

i The stress generators, for example, the vibrator, the noise generator, the hot chamber.

ii The stress inputs at subjects/machine/environment interfaces

iii The task and/or subject activity. Particularly define its relation to real life situations and, where task equipment is used, check the effect of environmental stresses on equipment performance *per se*. Consider the use of Wilkinson's[18] proposed or other standard tasks as a reference point in any major investigation.

iv Other environmental factors. Define their range if not deliberately controlled and varied in ii.

v Instrumentation and calibration

Item		Planning	Execution of experiment	Analyses	Reporting
Aims		✓			The lot!
Literature survey		✓			
Investigators		✓	✓		
Subjects		✓	✓		
Safety		✓	✓		
Equipment	Stress generators (vibrator hot chamber etc)	✓	✓		
	Seat (or subject/rig interface)	✓	✓		
	Environmental simulation and task	✓	✓		
	Instrumentation	✓	✓		
	Data recording	✓	✓		
	Data presentation and analysing	✓	✓		
Experiment	Calibration	✓	✓		
	Subject characteristics	✓	✓		
	Subject briefing	✓	✓		
	Psycho-physiological influences	✓	✓		
	Learning and acclimatization	✓	✓		
	Exploratory tests	✓	✓		
	Control tests	✓	✓		
	Main tests (experimental design)	✓	✓		
	Subject interrogation	✓	✓		
Analysis and significance of results	Data analysis	✓		✓	
	Statistical analysis	✓		✓	
	Discussion and conclusions			✓	

Fig.7 Experimental plan

c Subject definition

This is needed for 4 main reasons:

i To select subjects appropriate to the project. Physical, physiological and psychological data may be required (see d below).

ii To consider the application of results to a wider population.

iii To consider the application of results to other inputs.

iv To define subject capacity. This will often be covered by incorporating comprehensive control tests (see e below).

d Psychological aspects

Individual temperaments and experiences and situation factors such as, for transport, the nature of the vehicle, the purpose and cost of the journey, influence and may in fact largely control subjective reaction to a particular stress, as opposed to the direct physical and physiological inputs. Motivation is particularly important and for *ad hoc* laboratory work the aim should be to achieve something like the degree which is likely to occur in real life. Incentive, such as competition or reward may be desirable and accurate simulation will help. For basic work it may be desirable deliberately to vary the degree of motivation. Linked with motivation the relevance of subject versus operator control of the stress is important.

e Experimental procedure

Too often, in the author's opinion, have investigations ploughed straight into an elaborate, complex experimental design in the hope that many variables such as time of the day, order of presentation, learning effects etc will be balanced out. While such a design may eventually be worthwhile, particularly to investigate inter-subject variability, extensive exploratory testing on a limited number of subjects will generally be invaluable. These preliminary tests should aim to establish the likely critical variables, for example in vibration work, the seating position, posture, etc. In moving on to any balanced experimental design remember that such designs will not necessarily cancel out important effects such as those due to the intrinsic body or 'biorhythms'. There is a useful AGARD report[9] on the subject and an intriguing theory, which the author has not yet been able to explore fully, that man has considerable 'monthly' physical, emotional and intellectual cyclic variations (actually of 23, 28 and 33 day periods respectively). It is reported[10] that the Japanese OMI Railway Company has reduced accident rates of its operators by taking these periodic variations into account. Obviously the logical way to balance out as far as possible such known and unknown rhythms, and any more random variations due to emotional or physical upsets, is to compare performance with control (no stress) and stress tests placed as close as possible together. The importance of control tests, already underlined by Wilkinson[1] cannot be over-emphasised, since in many situations human response to environmental loading is rarely an absolute but rather a condition relative to the 'no stress' or more accurately, the normal environmental loading state. If this can be achieved without over-complicating the investigation, step by step control tests in which first one and then more environmental stresses are added, will obviously help in finding out the all important 'why' a particular reaction has occurred. Control tests in investigations of the effects of lengths of exposure should, of course, be carried out for the full duration of the exposure, not just before and after the exposure.

Other important aspects of experimental procedure include subject briefing and debriefing, indoctrination and training. Some of these are discussed in more detail with particular reference to vibration but with obvious, more general overtones, elsewhere[17].

f Analysis and significance of results

This may well be the most important yet often the most difficult and the most time-consuming part of the investigation. All the environmental stress inputs should be carefully analysed at the subject/rig or subject/environment interface. Regarding subject output performance, for some tasks the method of error scoring may be varied to give some indication of the effect of task severity without actually having to vary the task, for example, narrow versus broad band width errors on a driving task.

In many investigations some form of statistical analysis will obviously be desirable, firstly to explore mathematically any possible relationships between parameters such as vibration level, performance, time etc, which are not obviously apparent from inspection of results, and secondly to extrapolate results to cover a wider population. Unfortunately, in most investigations subjects are few, the number of tests limited and the results may be widely scattered. For such, statistical analysis should be used with caution, after first checking that the basic assumptions of the particular method chosen are valid for the data being examined. We must not forget that in human factors investigations we are rarely interested in mean population results. Particularly for military situations we need a much wider cover, usually ±2 SDs at least. It must not, however, be assumed that distribution is Gaussian - this may well be far from the case.

g Reporting

Inadequate reporting, concomitant in some cases with inadequate investigation, has probably been the greatest single source of difficulty in analyzing, applying and correlating the results of different single stress investigations. For compound strain work comprehensive reporting of investigations will be absolutely essential. As regards factual contents such as apparatus and method of test, the criterion for the report should be that it will enable any other worker, if he so desires, and if he can obtain the apparatus, to repeat the experiment in toto.

TWO COMPOUND STRAIN PROBLEMS IN URGENT NEED OF INVESTIGATION?

Notwithstanding the previous somewhat discouraging remarks about the difficulties of such investigations, the author suggests that two important problems of compound strains in urgent need of investigation are:-

a The effect of physical and mental loads on aural comprehension particularly in noise. That is effectively, the effect of other stresses on the signal to noise ratio for comprehension. Our present difficulties of communication in noisy military aircraft are complicated by lack of information on this problem. A practical example of our difficulties occurred during a practice bombing flight in an aircraft at a flight test establishment. The pilot was given a clear ground message during his bombing run 'not to drop bombs'; this was heard by the navigator but the pilot, presumably because of his intense concentration on his flying task, just did not comprehend and continued and dropped his bombs.

b Motion sickness is a widespread problem in many forms of military and civil transport, yet a study of the literature by the author and his colleagues in connection with the preparation of a BSI/ISO standard revealed a remarkable lack of information on the subject. Few worthwhile laboratory or field investigations seem to have been made to record and analyze the contributions made by vibratory motion and other relevant stress inputs, such as vision, heat and odours. One of the few useful field reports[19] gives some quantitative indication of the importance of compound strains. In a military troop transport ship pitching at about 0.17 Hz, a peak vertical g of ±1 m/s^2 caused about 12% of troops to be sick, whereas about 5% only were sick when the acceleration dropped to ±0.3 m/s^2 (both these figures applied to normal living accommodation). Sea-sickness however rose to 8% at only ±0.16 m/s^2 in the Mess Hall, although here exposure times were shorter.

CONCLUSION

Certain lines of attack have been suggested if we are to make effective progress in this very difficult area of compound strain investigations. Firstly, suggestions have been made concerning terminology and the term 'compound strains' is considered to be a more pertinent definition in many situations than the more-common 'combined stresses'. Secondly, using the problems of vibration as an illustration, suggestions have been made which will encourage efficient, consistent methodology and reporting, and hence help to avoid the confusion apparent between the results of many single strain investigations. Thirdly, two compound strain situations worthy of early attention have been outlined.

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DISCUSSION

HOWARD It seems to me that one of the things that's being complained about in this paper is that the author cannot go to the literature and find definitive answers to complex questions. They are saying that when they look at, for example, human tolerance to vibration, they find a number of figures which appear to be contradictory. This, I think, probably stems in fact from one of their recommendations quoted in the paper which is that we should encourage more field, particularly real life, investigations. The difficulty, it seems to me, in many of these areas is that people have gone into the field and they have examined real life situations without proper control. These have been ad hoc experiments. Now, those of us who are biologists realize that the human body is a complex thing composed of a number of imperfectly analyzed systems and that no two human bodies will react in the same way. They are not like engines or mechanical devices. Those of us who are in the aerospace physiology realize also that when one tries to combine more than one stress, advertently or inadvertently, the difficulties multiply. It's not simply as a multiplication fact but probably a power law. To me, the whole argument is summed up by one sentence on page 3, which says, "exit vibration engineer in complete confusion". Well, I am not one bit surprised because it seems to me that the vibration engineer usually lacks both the understanding and humility which is essential for any biological investigation. Thank you.

ALLEN I think if we are not careful, of course we shall run into accounts of despair on this situation. We discuss this topic in the paper, in an attempt to drive home to those involved, be they engineers, physiologists, psychologists or instrumentation experts (and I think in many investigations we need a team composed of all these disciplines) just what they are up against - just what an incredible number of variables are involved. This is difficult enough in the laboratory and in fact I think Dr. Grether, Dr. Guignard, Dr. Harris and Dr. Schoenberg, and many other authorities have acknowledged that there has been inadequate methodology. By all means, let us endeavor to improve this understanding. Let's at least know the variables involved and let us work together to see if we can improve the situation. We don't even yet know how to measure the input of vibration to the human body - let alone how to investigate what reactions it produces on this body.

A FLIGHT TEST PROGRAMME TO STUDY THE EFFECTS OF ENVIRONMENTAL STRESSES ON AIRCREW OPERATING MILITARY STRIKE AIRCRAFT*

by

Squadron Leader M.G. Trumper, C.Eng., M.I.Mech.E., A.F.R.Ae.S., RAF,
Human Engineering Division, EP Dept.,
Royal Aircraft Establishment, Farnborough, Hants

SUMMARY

Military aircraft operations for this decade, and probably the next, include a major contribution from strike aircraft. Such aircraft, with their ability to strike at high-speed and low-level, must therefore be the subject of intensive study by those concerned with human factors thinking and planning if human problems in their operation are to be avoided. These studies include the collection of flight test data on which to base realistic laboratory experiments which, in turn, lead to realistic specifications for cabin environments.

This paper describes a flight test programme designed to obtain objective measurements of noise, vibration and temperature throughout typical profiles flown by military strike aircraft, and, as far as is possible, to correlate the measurements with aircrew reaction and performance. As a secondary object the programme will investigate the usefulness of a water-cooled suit installation as a means of relieving aircrew thermal stress in strike aircraft.

INTRODUCTION

There can be little doubt that one of the most useful contributions which those studying human factors problems during the 1970s can make in the field of military aircraft operations must be directed towards strike aircraft. These aircraft, with their ability to strike at high-speed and low-level beneath the defensive lobes of enemy radars, are recognised as essential in military aircraft strategy certainly for this decade and probably the next. In Europe development of the highly sophisticated MRCA is evidence of this while a recent article[1] describes the early development of the North American-Rockwell B1 indicating similar thinking in the United States. If these aircraft are examples of those which will be in operational use at the turn of the decade, then human factors thinking and planning for the 1970s must be concerned to a considerable extent with the operation of such aircraft types. With this in mind when one looks at the facilities available for such studies one is struck by the fact that there are ample laboratory facilities, but few for collecting the flight test data on which to base realistic laboratory experiments. This clearly is a weakness, since, in the absence of realistic objective data, it is almost impossible to discuss human factors problems with those concerned with future requirements. This is especially true of strike aircraft, for example, it is only the occurrence of severe problems of communication in the high noise environments in existing strike aircraft which has led the UK to undertake an intensive study of the noise problem. Far better if such a problem could have been detected during the early stages of research and design instead of in the final operational aircraft. Among other important factors, very little is known of the effect of vibration on the aircrew operating such aircraft, while earlier work completed in the late 1960s[2] has sounded warning of thermal stress problems. There is therefore a very real case for investigating the influence of the total environment (noise, vibration and temperature) on the aircrew required to undertake the operation of military strike aircraft.

Recognition of this has led RAE to acquire a flight test vehicle in which to collect objective and subjective data. Such data are urgently required as a basis for laboratory experiments, and to assist in the preparation of more realistic specifications for cabin environments.

AIM OF THE PROGRAMME

The aim of the flight test programme to be undertaken by the Human Engineering Division of the Royal Aircraft Establishment, Farnborough and the RAE Bedford is to obtain objective measurements of noise, vibration and temperature throughout realistic profiles flown by military strike aircraft, and as far as is possible to correlate them with aircrew reaction and performance. As a secondary aim the usefulness of a water-cooled suit installation as a means of relieving aircrew thermal stress in strike aircraft operation will be explored.

THE FLIGHT TEST PROGRAMME

In order to ensure that the data collected have meaning in the operational situation, and hence to ensure that any specifications developed from such data may reasonably apply to future operational requirements, a study has been made into the conduct of current strike aircraft training operations as carried out by the Royal Air Force in Europe. These studies have confirmed the very exacting task which aircrew are required to perform despite the unfavourable environment of the cockpit in which they must work. The studies have highlighted the terrain problems which strike aircraft could face, the geographical features which could be exploited, and the many other facets which could form the background of strike aircraft operations in the 1970s. In this way sample flight test routes have been established which will form the basis for the operation of the flight test vehicle and which will require a performance from the test aircrew similar to that required from their operational colleagues.

The flight test vehicle is a Phantom YF4K. This aircraft is considered to be a good choice for a number of reasons, perhaps the most important of which is that it is representative of existing aircraft

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types and similar to future types. Additionally the high performance capability of the aircraft will ensure that the flight test aircrew are fully stressed when undertaking the realistic sorties which are the basis of the programme.

The flight test programme will involve collection of data over a period of 160 flying hours. During this time it will be possible to collect enough data to define the environmental stresses to which the aircrew are subjected. At the same time it is hoped to measure certain crew/aircraft performance and physiological parameters which will highlight the more stressful parts of the sorties. In this way it will be possible to determine the environmental conditions obtaining during times of high aircrew stress, and this is the type of information which should form the basis of laboratory experiments. Subsequent processing, categorisation and presentation of the data collected will provide for a successful transition from the flight situation to the laboratory situation.

THE FLIGHT TEST INSTRUMENTATION

The data collection system provides for the acquisition of noise and vibration data. The primary system is a 14 channel magnetic tape recorder operating in its analogue mode. Ten transducers provide acoustic information to the recorder, while vibration information is obtained from 12 accelerometers mounted in 4 blocks of 3, each block measuring the acceleration in orthogonal axes at a point. Additionally the instrumentation design provides for a back-up and quick-look facility. This is achieved by the use of an AM single channel tape recorder receiving sequenced information from each of the 10 acoustic transducers, and by a 4 channel FM recorder receiving information from the accelerometers. Data for subsequent analysis and categorisation will, in the main, be collected on the primary system. A schematic diagram of the instrumentation is given in Fig.1.

NOISE ASPECTS OF THE PROGRAMME

The transducers for the acoustic work consist of 3 half-inch condenser microphones carefully positioned in each cockpit. Additionally two miniature microphones will be mounted on each of the pilot's and navigator's helmets, such that one is positioned in the inner cavity of the ear defender and the other is positioned on the outer shell of the helmet. This distribution of the 10 microphone channels available will enable many aspects of the acoustic environment to be monitored. The simultaneous recording by the multi-channel tape recorder will enable a full analysis of the noise environment to be carried out, and application of techniques such as correlation will lead to a better understanding of the way in which the noise environment is created. From such information it will be possible to suggest design and manufacturing techniques aimed at minimising environmental noise levels. Other work which the instrumentation will allow includes: the validation of techniques of noise level prediction from theoretical data, objective measurements of helmet attenuation aimed at optimising the acoustic performance of headgear, and the validation of specifications for maximum allowable noise levels in crew compartments.

VIBRATION ASPECTS OF THE PROGRAMME

In a recent paper[3] G.R. Allen discussed many of the problem areas associated with studies completed to date of human reaction to vibration. Important amongst his findings were criticisms of the proposed ISO limits which included, quote "it is understood that the limits have been derived mainly from laboratory evidence much of which in the author's view is of uncertain validity and of doubtful relevance to the real life situation". Amongst Allen's conclusions was the recommendation to encourage more field, particularly real life, investigations as frequently only these can provide realistic evidence on human reaction to vibration. Clearly there is real need to collect data in flight to check the relevance of laboratory studies before design specifications can be developed and approved. Some work[4] has recently been completed in the USA to this end and the UK flight test programme will take note of the findings of this work; however an essential difference between the two studies will be in the flight test profiles used to collect the data. The instrumentation used will monitor the transmission of vibration from the structure to the man. It will consist of two banks of 3 accelerometers measuring longitudinal, lateral and vertical accelerations, fixed to the aircraft structure close to the seat and to 'the seat of the pants' of the aircrew member. This instrumentation layout will be followed in both pilot's and navigator's cockpit. The outputs from the accelerometers will be fed to either the 14 channel recorder or to the 4 channel recorder. Data analysis will include peak counting, probability density and distribution, and power spectral density. Later work will include instrumentation to monitor roll, pitch and yaw, angular accelerations, and to investigate transmission factors between 'the seat of the pants' and the head of the aircrew members.

THERMAL STRESS ASPECTS OF THE PROGRAMME

It has been stated by Aero-Medical authorities[5,6] that a subject is in a state of thermal comfort when his mean skin temperature is 33°C. With this as a basic criterion Hughes[7] has studied the cabin air requirements for crew comfort in military aircraft. He found that the influence of cabin air distribution on the air requirements for comfort is considerable, while other factors which influence cabin air requirements for thermal comfort are the mean work rate of the crew (a factor influenced by cockpit layout) and the clothing assembly. These latter points can only be truly assessed by flight test work. Modern designs for cabin conditioning systems based on these earlier studies suggest they are unlikely to be able to produce the cockpit thermal environment necessary to meet the comfort requirements over the necessary range of controlled cockpit temperature. To obviate this, and also to provide for those occasions when the cabin conditioning system cannot cope (such as on the ground or whilst taxying), and further to provide for those occasions when special protective clothing such as CW clothing or pressure clothing is required, some form of personal conditioning system is essential. In the UK the choice for such systems lies between the air-ventilated suit and the liquid-cooled suit - the former being already in use whilst the latter is in an advanced stage of development. In a recent combined exercise[8] the RAF Institute of Aviation Medicine and the RAE undertook a laboratory comparison of three methods of personal conditioning. The report of this work indicated that the liquid-cooled suit was the preferred method for personal conditioning, subject to the development and testing of an aircraft supply system and to the acceptability of the complete system to aircrew under realistic field conditions. The liquid-conditioned suit has already completed satisfactory flight trials in the Shackleton and Canberra aircrafts (and, of course, in Apollo and on the moon!) but it has yet to be proved as suitable for strike aircraft. The thermal stress aspects of the Phantom flight test programme will be, therefore, to explore the usefulness of a liquid-cooled suit installation in a realistic operational environment. (In this way it should be possible to demonstrate a system, which has been shown to have advantages under laboratory conditions, to those responsible for future requirements; and at the same time to move towards aircrew acceptance of a viable alternative system of personal conditioning.)

THE PROBLEM OF MEASUREMENT OF AIRCREW PERFORMANCE

Anyone concerned with environmental aspects of human factors work must be interested in relating human performance to the environment in which the performance is achieved. Ultimately the goal would be to correlate performance, particularly any degradation of performance, with the environmental stresses. Some effort to this end will be included in the investigation. To expect to correlate performance precisely with environmental conditions is clearly impossible - there are so many physiological and psychological factors which influence human performance, to say nothing of the physical factors such as (in the flight case) weather conditions - that any attempt to do this would be meaningless. Relating performance to the environmental conditions has some chance of giving results but even then great care must be taken to recognise the limitations of any analysis.

What is practical in a flight test programme, and which can be used as a measure of satisfactory aircrew performance, is the achievement of a goal such as the successful acquisition of a target at a pre-planned estimated time of arrival (ETA). This situation would equate to a military strike aircraft operation in which the object is to arrive at a fixed point (the target) within a certain period (the planned ETA) after navigating a route of variable length. The environmental data collected on such a sortie can then be said to be data obtained during a satisfactory aircrew performance. In the flight test programme, data collected for subsequent analysis will only be taken from such flights. If the stressful areas of these flights can be found it is possible to limit the analysis to consideration of the environment obtaining during periods of high stress, on the grounds that the environment is likely to be most detrimental to performance at such times. In this way an adverse environment related to satisfactory aircrew performance under stress can be found.

The intention is to determine the stressful areas of the operational flight profiles by the measurement of physiological parameters, probably heart rate. This aspect of the programme will be supervised by a physiologist with appropriate aviation medicine specialisation. Additionally some idea of comparative stress levels will be explored by use of bio-chemical techniques.

At a later date consideration to the introduction of variables into environmental stress conditions will be given. Some thoughts will also be directed to the possibility of using aircrew/aircraft control measurements as parameters in the assessment of aircrew performance.

AIRCREW PARTICIPATION

Some mention must be made of the aircrew who will participate in the flight test programme. The aim of the programme is to determine the environmental stresses on the aircrew during satisfactory military strike aircraft operations. Consequently the pilot and navigator will be doing more than flying the aircraft to set up the environmental conditions. They will be the subjects of the exercise, and as such their skill and navigation to achieve the task (i.e. the navigational goal) are all-important. For these reasons aircrew with experience of the highly skilled, high-speed low-level operation of high performance aircraft, and sympathetic to the task, will be used during the programme in order to avoid the accusation of meaningless results produced by untypical aircrew. Further, by the use of representative operational routes, the dangers of obtaining information from unrepresentative flights will also be avoided.

CONCLUSIONS

This paper has set out the reasons why a flight test programme is important in studying human factors problems during the 1970s. The case for such a programme to be based on realistic operational flight profiles in aircraft flown by representative operational aircrew has been developed. The factors to be measured have been described and some thoughts on the measurement of aircrew performance have been given. These points together form an interesting and potentially exciting exercise, but over and above this will provide the opportunity for those studying human factors problems to base their findings on field and not just laboratory data. Furthermore the specifications which will be developed will apply to actual operational situations, thus strengthening the arguments for considering human factors in the compromises inevitable in the design of new aircraft.

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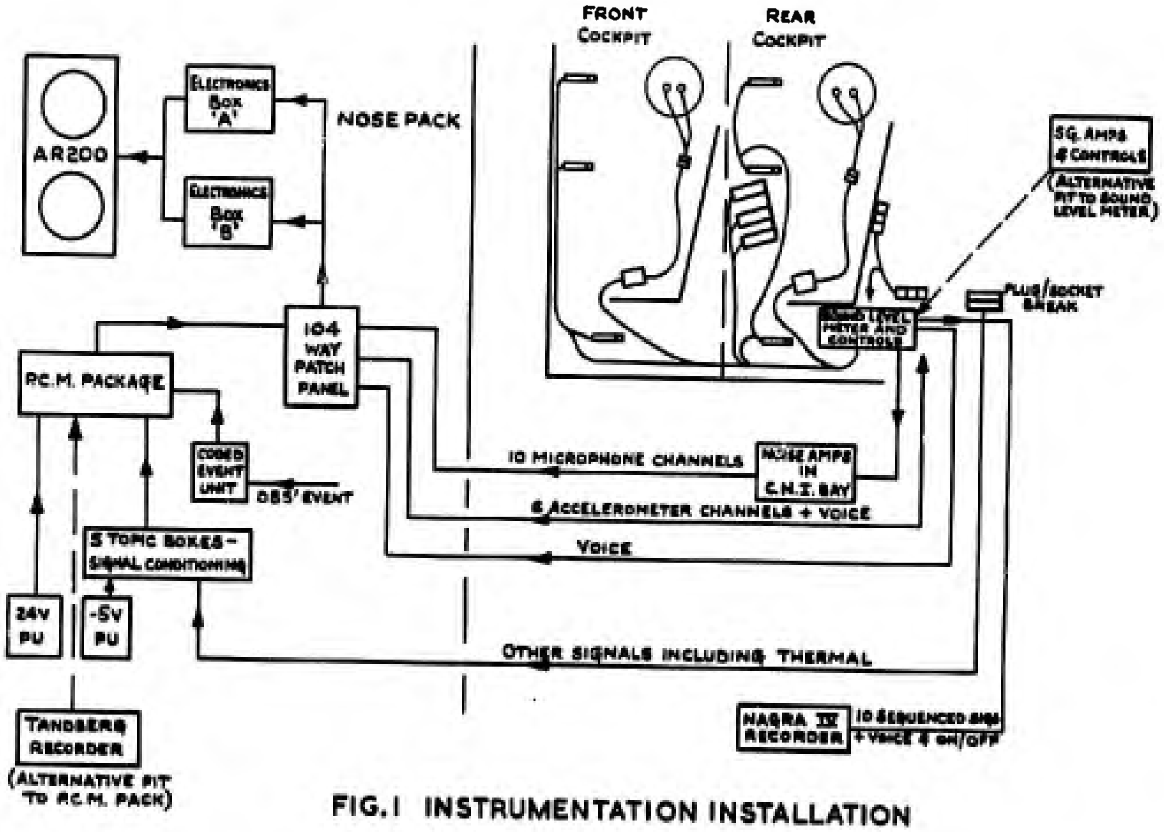

FIG.1 INSTRUMENTATION INSTALLATION

DISCUSSION

FURR

Do you feel that the removal of the radar to accommodate the bioinstrumentation package in the test F4-J/K aircraft has an effect on the performance criteria secondary to environmental stresses evaluated. The point being that since the RIO (aft seat operator) cannot use radar, is the evaluation of his performance representative of the real world?

TRUMPER

Despite the fact that we have had to remove the radar package from our flight test aircraft, our studies of strike aircraft training operations have shown that the remaining navigation aids carried by the aircraft will still enable a representative operational flight profile to be flown. Additionally, of course, aircrews still rely heavily on visual map reading techniques to support the information they are being fed by the aircraft navigation aids, and in some cases visual map reading techniques are the primary means of navigation.

FROHLICH

You are involved now with more or less the operational side of hearing and communication. Are you also intending, in your experiments, to study the influence of the hearing on these experiments? Will you use pilots with normal hearing and pilots having, let's say, a high high-tone hearing loss to see how this influences your experiments? Such experiments would have an influence on our hearing standards for pilots.

TRUMPER

The aircrew who will be used during our flight test experiments will be normal aircrew and as such their aircrew medical category will exclude significant high tone deafness.

TWO EXPERIMENTS ON THE EFFECTS OF COMBINED HEAT, NOISE AND VIBRATION STRESS*

Walter F. Grether, PhD
Aerospace Medical Research Laboratory
Aerospace Medical Division
Air Force Systems Command
Wright-Patterson AFB, Ohio, 45433, USA

Operational flying often exposes crew members to combinations of environmental stresses that may affect flight personnel differently than would be predicted from single-stress laboratory experiments. To obtain a better understanding of such combined-stress effects a major experiment was conducted using heat (120° F), noise (105 dB), and vibration (5 H_z, 0.30 peak g), both singly and in combination. Measurements were made of tracking ability, choice reaction time, voice communication, mental arithmetic, visual acuity, body temperature, heart rate, weight loss, and subjective ratings of the stress. On none of these measures did the combined triple-stress-condition produce greater effects than did the most severe single stress. On the physiological measures only heat stress produced significant effects, and the addition of noise and vibration produced no further effects. On the performance measures, particularly the tracking test, impairment was slightly less for the triple-stress condition than for vibration only. Thus there were no additive interactions, and in fact some evidence of antagonistic interactions. As a check on these results a second experiment, with slight modifications was undertaken. This experiment yielded essentially the same results.

INTRODUCTION

Considerable laboratory research has been devoted to flight environmental stresses and their effects on aircrew performance. But in most of the past research these stresses, such as hypoxia, heat, noise, acceleration, and vibration, have been studied singly rather than in combination as they frequently are experienced in flight. The possibility exists, therefore, that the combinations of stresses as they occur in flight could cause physiological disturbances and performance impairment that are more severe than would be predicted from the usual single-stress studies in the laboratory.

The possible effects of stress combinations and some experiments involving combined stresses have been discussed by Broadbent (1) and Wilkinson (2). Also, reviews of the fairly limited number of experiments using combined-stress exposures have been prepared by Murray and McCally (3), and Grether (4). In terms of gross effects on performance, there are four general outcomes that would be expected from the combining of environmental stresses. These are: (1) No effect - Effects no more severe than produced by any of the stressors acting singly, (2) Additive effect - Effects greater than those from the most severe stressor acting singly, but not greater than addition of effects from single stressors, (3) Greater than additive - Effects greater than mere addition of single-stress effects (also called "synergistic"), (4) Subtractive effect - Effects less than those produced by the most severe single stressor (also called "antagonistic").

From the reviews of previous experiments the most common findings have been no effects or merely additive effects from combining of stresses. While there have been some quite clear findings of subtractive or antagonistic interactions, effects on performance that are greater than additive seem relatively rare. It is such greater than additive or synergistic effects, of course, that would be of greatest scientific and operational significance. If there are severe effects that cannot be reliably predicted from single-stress experiments, they could cause serious and unknown flight hazards.

Although the past experiments give us some assurance that combinations of stresses do not present a common flight hazard that is unpredictable from single-stress studies, they also give us some warning flags

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*This paper is based upon two experiments conducted as a team effort and published in full elsewhere (see references 12, and 13). The additional authors on the original papers are C. S. Harris, J. C. Guignard, G. C. Mohr, C. W. Nixon, M. Ohlbaum, H. C. Sommer, V. H. Thaler and J. H. Veghte. The research was conducted at the Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. This paper has been identified by the Aerospace Medical Research Laboratory as AMRL-TR-71-113. Further reproduction is authorized to satisfy needs of the U. S. Government. The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 80-33.

that need further study. Let me illustrate this with some results of experiments with combinations of heat and hypoxia. A study by Chiles, et al (5), used a combination of 14,000 feet and 60° C, with 30-minute exposures. The combination of heat and hypoxia caused no greater impairment of performance on tracking, monitoring, and arithmetic tests than did hypoxia alone. Allnutt (6), using a combination of 10,000 feet altitude and 34.4° C effective temperature during 90-minute exposures found only a slightly greater effect on an intelligence test from the combined stress than from either stress singly. In a later experiment Allnutt (7) tried a combination of 15,000 feet and 34.4° C effective temperature. Using this combination he was unable to complete the experiment, because of physiological inability of the subjects to tolerate this combination. Individually these stresses were quite tolerable, but in combination they were not. What Allnutt's experiment suggests is that the outcome of combined-stress experiments depends very critically upon the severity of the individual stresses in the combination. Thus, conclusions based upon combinations of moderate stress levels may tell us little about effects from more severe combinations.

From the evidence to date the problem of combined stresses appears to be complex, and a great variety of experimental outcomes are possible. Whether the combined-stress effects are additive, synergistic, or antagonistic seems to depend not only on which stresses are being combined, but also on the nature of the tests that are used, and the levels of the individual stresses. For an ultimate understanding of what happens when aircrew members are exposed to combined stresses we need a better understanding of the underlying physiological and behavioral mechanisms.

As a major experiment on the effects of combined stress in our laboratory, we chose a triple combination of heat, noise, and vibration. This choice was based primarily upon the facilities readily available to us, rather than scientific or theoretical considerations. The choice of these three stresses can be defended, however, on the basis that they are very likely to be encountered in military flights. For these three environments we know of no common, specific underlying mechanisms that would lead us to predict either synergistic or antagonistic effects. Any additive effects would presumably result from general, non-specific stress experienced by the subjects.

As far as we know there have been no previous experimental studies using triple-stress combinations of heat, noise, and vibration. There have, however, been experiments using two-stress combinations of heat and noise by Viteles and Smith (8) and Dean, McGlothlen, and Monroe (9). Combinations of noise and vibration have been studied in our laboratory by Harris and Shoenberger (10) and Harris and Sommer (11). These previous studies have demonstrated some additive effects, and in some instances no special effects from these combinations.

Using a combination of heat, noise, and vibration we have conducted two separate experiments described in this paper. Further details concerning these experiments can be found in two reports by Grether, et al. (12, and 13).

EXPERIMENT 1

EXPERIMENTAL FACILITY AND STRESS CONDITIONS

In order to provide a combination of heat, noise, and vibration, a temporary heat enclosure was constructed around the subject's seat on a mechanical vibration table (Western Gear High Amplitude Vibration Machine). Enclosed with the subject were the displays and controls of the apparatus used to measure subject's performance. The enclosure, however, was supported on the floor of the room and did not vibrate with the seat. Temperature control was obtained by recirculating electrically heated air through the enclosure. Humidity of the air was monitored but not controlled, and airflow was 80 feet per minute. Noise and voice communication inputs to the subject were provided through a military-type headset and microphone. The subject was thermally isolated from the metal seat by rigid insulation, wore lightweight flight clothing, and was restrained in the seat by a lap and shoulder harness.

For each of the stresses there were two conditions, one to represent an ambient level, and another to represent a level high enough to be stressful, yet known to be tolerable for fairly long term exposures. The exposure values were:

Heat	72°F	and	120°F (ET 88°F)
Noise	85 dB	and	105 dB
Vibration	0	and	0.3 g at 5 Hz

Of the eight possible combinations of the three stressors at two exposure levels, only five were used in this experiment. These were a control condition, three conditions using only a single stressor (heat, noise, or vibration singly), and a combined triple-stress condition.

PHYSIOLOGICAL MEASURES

Body temperatures of the subjects were monitored by thermistors at 17 skin locations, and by a rectal thermometer. Heart rate and weight loss were also measured.

PERFORMANCE MEASURES

Several different measures of subject performance were obtained. These were:

1. Compensatory pursuit in both the vertical and horizontal dimensions.

2. Choice reaction time to the onset of any one of three red lights, and to the extinction of any one of three green lights.

3. Voice communication that required the subject to repeat five-word phrases from the ICAO phonetic alphabet that he received through his headset.

4. Mental arithmetic that required the subject to mentally add columns of five two-place numbers shown on a rear projection screen.

5. Visual acuity for Snellen letters projected on the same screen and adjusted in size by the subject to define his own threshold.

Of the above tests, the first three were performed concurrently, requiring the subject to divide his attention among the different tasks. In addition, a rating scale was filled out at the end of each experimental session to obtain the subject's subjective evaluation of the stresses.

SUBJECTS

Ten male military personnel served as subjects. All were volunteers, were medically screened, and were given hazardous duty pay for serving in the experiment.

EXPERIMENTAL DESIGN

As preparation for the experiment, each subject was given two half days of training on the performance tests, during which he was given a short sample of each of the environmental conditions. After that the subject made five experimental runs, each with a different stress combination. All runs were separated by at least two-day intervals. The sequence of runs by different subjects was counterbalanced to compensate for learning or other similar effects.

Each run had a duration of 130 minutes. The critical stress exposure period occurred for 35 minutes, between 60 and 95 minutes after the beginning of the run. Performance tests were given before, during, and after the critical exposure period. The temperature stress, when included, always began at time zero, and lasted for 95 minutes. The noise and vibration stresses began at 60 minutes and lasted 35 minutes.

RESULTS FOR PHYSIOLOGICAL MEASURES

Results of the physiological measurements are summarized in fig. 1, 2, and 3. Only the heat and combined conditions showed significant effects by comparison with the ambient or control condition. These effects were increases in skin and rectal temperature, weight loss, and heart rate. It is of particular interest that the values for the combined condition match very closely those for the heat-only condition, indicating no added effects from the triple-stress combination.

RESULTS FOR PERFORMANCE MEASURES

Performance test results are summarized in fig. 4, 5, 6, and 7. The major effects were obtained for vertical and horizontal tracking, reaction time to extinction of green lights, and visual acuity. Not shown are results for speech intelligibility, reaction time to red lights, mental arithmetic, and subjective judgements for which results were not statistically significant.

From the results, the primary impairment of performance was produced by vibration. The heat also appeared to cause some minor impairment of tracking ability, and both the heat and noise caused an increase in reaction time to extinction of the green lights. Of particular interest, of course, are the results for the combined (triple-stress) condition. For none of the seven measures did the poorest performance occur during the combined-stress condition. For the two measures of tracking the average errors were distinctly less during the combined-stress condition than during the vibration condition. Although much of these differences resulted from one deviant subject, the mean errors for vertical and horizontal tracking are still greatest for the vibration-only condition, even when the data for the deviant subject are dropped.

Clearly the results of this experiment showed no additive effects from combining the three stresses. It appeared, on the other hand, that the addition of heat and noise to vibration somehow attenuated the effects of the vibration. This would be a subtractive or antagonistic effect. While for none of the measures were the differences between the combined and the vibration conditions large enough to be statistically significant, the consistency of this finding across performance measures makes it hard to dismiss.

A finding of an antagonistic effect was quite contrary to our expectations prior to conducting the experiment. In our consideration of possible mechanisms to account for a slight antagonistic rather than the expected additive effect, two possible explanations were seriously considered. The heat, or less likely the noise, through muscular relaxation might have caused less vibration to be transmitted to the body and limb of the subject. A second possibility was that the motivation of the subjects was greater during the combined than during the single-stress runs. Since the stress conditions could not have been concealed from the subjects, they were always informed in advance of the conditions. Also, a medical monitor was always present during the combined-stress runs, but not during the single-stress runs. To provide a test of these two possible explanatory mechanisms, and also as a general check on the findings of the first experiment, a second experiment was conducted.

EXPERIMENT 2

The second experiment was conducted in the same facility and used the same three environmental stresses, stress levels and physiological measures as experiment 1. Modifications were made in some of the performance tests and in the experimental design, as explained below. Added to the experiment was instrumentation for recording vibration amplitude on the right shoulder of the subjects. This provided a test of the hypothesis that the noise or heat somehow reduced the vibration transmitted to the subject. Another change was the avoidance of all on-site medical monitoring. This served to reduce inequalities in subject motivation during different exposure combinations, as a partial test of the hypothesis that subjects tried harder during the combined-stress condition.

CHANGES IN PERFORMANCE TESTS

No changes were made in the tracking, choice reaction time, and visual acuity tests. Instead of the voice communication test concurrent with tracking and reaction time, we used a telephone test. This also was administered through the aural and voice channels, but required the subject to answer yes or no to simple questions involving logical alternatives. To somewhat increase the difficulty level of the mental arithmetic test, the subjects were required to subtract 13 from each sum before reporting their answer. Changes were also made in the methods for obtaining subjective ratings of the stress conditions, so that ratings were obtained several times during as well as at the end of each experimental run.

CHANGES IN EXPERIMENTAL DESIGN

Only four stress combinations were used: (1) control, (2) vibration only, (3) heat and vibration, and (4) heat, noise, and vibration. Again, all subjects were run on each stress combination with suitable counterbalancing of the sequences to compensate for learning effects. Within each experimental run the sequence of events was the same as in Experiment 1, except that the post-exposure testing was omitted, thus cutting the total time for each run to 95 minutes. There were 12 subjects.

RESULTS

As in the first experiment the physiological measures, skin and rectal temperature, heart rate, and weight loss, were affected only by the heat stress. As in Experiment 1 combination of heat with noise and vibration produced no additional increases in the physiological indicators.

Our chief interest was in the performance measures. For these the results of primary interest are shown in fig. 8,9,10,11, and 12. The data for vertical tracking clearly show maximum impairment for vibration only, somewhat less impairment for the double combination of heat and vibration, and still less effect from the triple combination. The same general result appeared for horizontal tracking, although the differences between stress conditions are less pronounced. The data for choice reaction time to extinction of green lights shows the same trend, although the differences are very small. For reaction time to red lights the data look very similar, with the least impairment from the triple combination. Only for reaction time to red lights was there a statistically significant difference between the means for the vibration only and the triple-stress condition.

Recordings of vibration amplitude, in terms of peak acceleration, at the subjects' right shoulder showed no effects from adding heat and noise. The amplitude at the shoulder, because of body resonance, was somewhat greater than the vibration input of 0.3 g. There was, however, no indication that the vibration at the shoulder was either attenuated or increased by the heat and noise.

Unlike the performance test data all the subjective ratings of stress severity showed a trend upward as the number of stresses was increased.

DISCUSSION OF RESULTS

Before conducting these experiments we had assumed that combinations of these three environmental stresses would produce some additive effects on performance. This had been the most common finding of the limited number of previous combined-stress experiments including those involving combinations of heat and noise, and noise and vibration. The results of Experiments 1 and 2 are very clear, however, in showing no evidence of any additive interactions of stress effects. On the contrary the performance data from both experiments show that the greatest impairment of performance is caused by vibration only. The performance impairment is consistently less when heat and noise are added to the vibration stress. Although the differences generally are not large enough to be statistically significant, the consistency of the results for different performance tests, in both experiments, would seem to make the null hypothesis untenable.

Considering the overall data, I believe the most defensible conclusion is that the combination of heat, noise, and vibration is less disturbing to performance than is vibration alone.

Our attempt to identify an explanatory mechanism for the apparently antagonistic interaction among the three stressors was unsuccessful. Measurements of the vibration transmitted to the subject did not indicate that vibration was attenuated by the heat and noise. Nor did our attempt to equalize motivational factors for the four experimental conditions eliminate the apparently antagonistic interaction among the stresses.

I would hesitate to draw generalizations from these two experiments concerning the more general problem of what happens when stresses are combined. At least two features of the combination we used are worthy of note. First, the stressors were quite unequal in their effects on tracking performance, the test which showed most clear indications of antagonistic interactions. As single stressors, heat and noise caused little if any impairment of tracking. In view of this it is surprising that the large effect produced by vibration alone was noticeably reduced under the combined-stress condition. A second feature of the stress combination in these experiments is that we know of no common causative stress mechanisms among the three stresses. Had all of the stressors operated through a similar physiological mechanism, such as a depressant action on the central nervous system, there would have been much more reason to expect additive or greater than additive effects.

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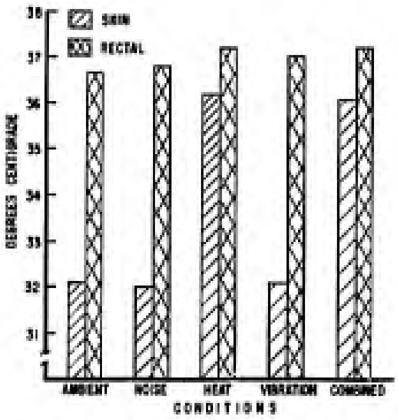

Fig. 1 Rectal Temperature and Mean Skin Temperature (Exp. 1)

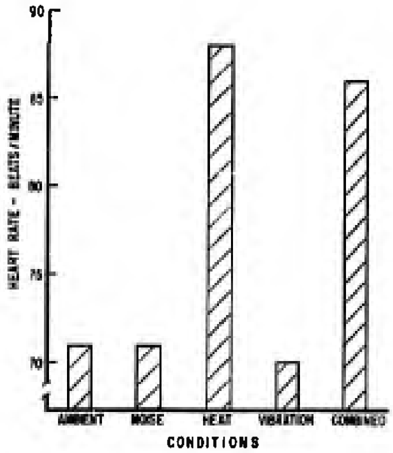

Fig. 2 Heart Rate (Exp. 1)

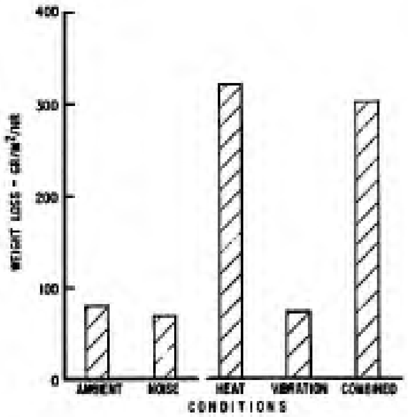

Fig. 3 Weight Loss (Exp. 1)

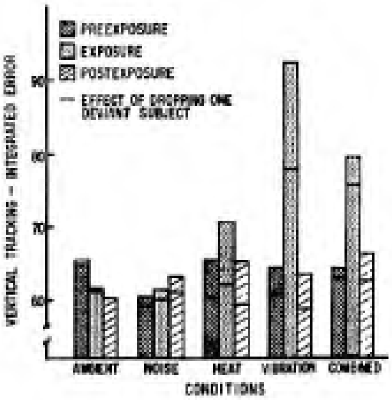

Fig. 4 Vertical Tracking Error (Exp. 1)

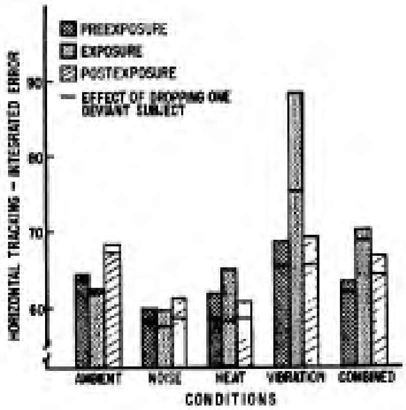

Fig. 5 Horizontal Tracking Error (Exp. 1)

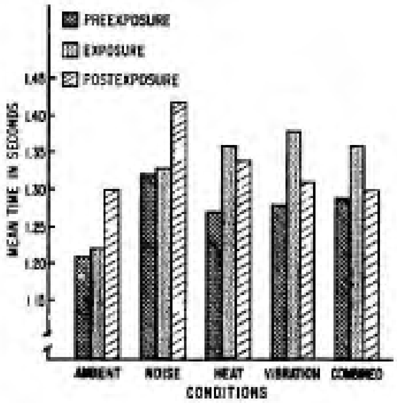

Fig. 6 Reaction Time to Extinction of Green Lights (Exp. 1)

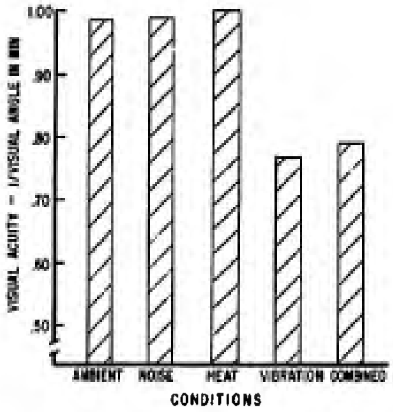

Fig. 7 Visual Acuity (Exp. 1)

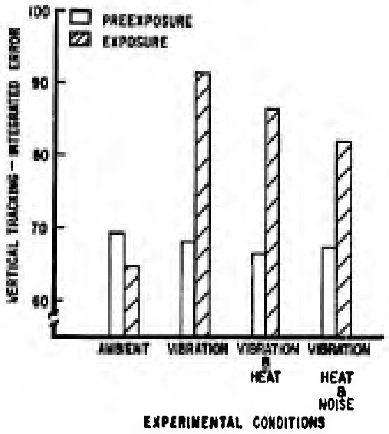

Fig. 8 Vertical Tracking Error (Exp. 2)

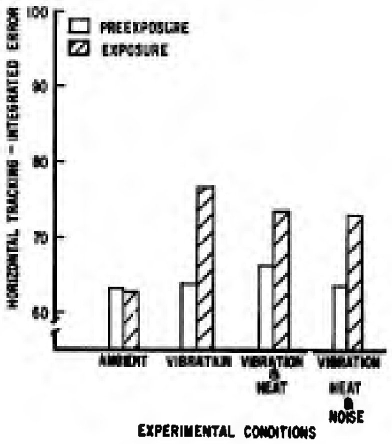

Fig. 9 Horizontal Tracking Error (Exp. 2)

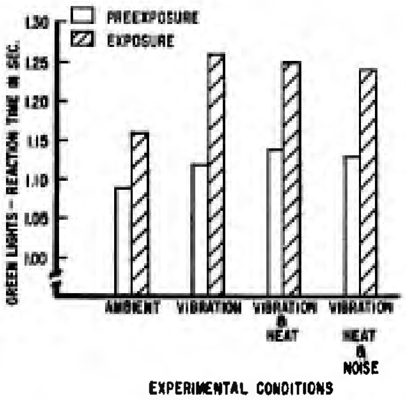

Fig. 10 Reaction Time to Extinction of Green Lights (Exp. 2)

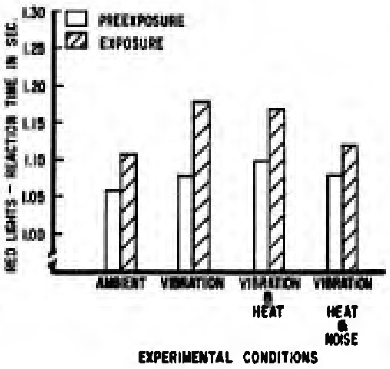

Fig. 11 Reaction Time to Extinction of Red Lights (Exp. 2)

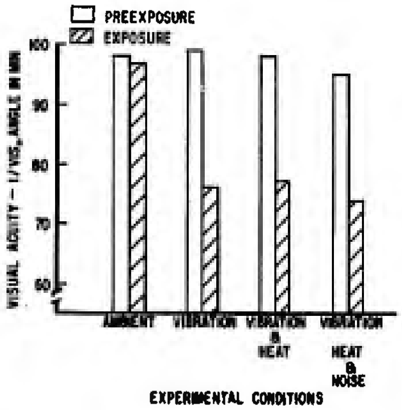

Fig. 12 Visual Acuity (Exp. 2)

DISCUSSION

WHITESIDE I'd like to ask Dr. Grether if he thinks that this effect which is not showing any statistical significance, but looks as though it is there, and I wonder could this be associated with the interest factor which was implied in your other assessment of these people, much in the same way as one listens to a story, for example, or one hears somebody talking and if one is trying to carry out mental arithmetic or some mental thought process requiring considerable attention, performance usually goes down, whereas if the intruding speech is in an incomprehensible unknown language, as far as the individual is concerned, this would probably have less effect on his performance. So, what I'm suggesting maybe is that where there is one stress on its own, it claims more attention rather than when it's mixed up with various other stressors. Just a suggestion; I would like your comment.

GRETHER It is quite possible that when the man was also hit by the noise and the heat; he didn't mind the vibration quite so much; he wasn't quite so aware of the vibration; however, it's hard to see why this would have made his tracking performance better.

PERRY Could the fact that your subjects were trying harder, because they had been through it all before, have had some sort of effect on the results? Or was an adaptive tracker or something used so that they couldn't forecast at all?

GRETHER I didn't explain this but these conditions were run in controlled order so that there could have been no learning effects. They were not run in the sequence in which they were listed on the slide. There could have been motivational effects. It could be that under the triple stress condition they tried harder, to try to prove to us and to themselves that they could take it. That's very likely the case; we have no way of ruling it out.

DICKERSON What were your criteria for choosing the particular levels of stress?

GRETHER A very appropriate question. We spent a lot of study and effort picking out the stress levels. First of all, we wanted levels that were known to produce effects. Secondly, we did not want to choose levels which were so high that we might run into difficulties of any kind in overstressing the subjects. So it was kind of a compromise between where we were quite sure there would be some effect from the stresses individually and where they were not so high that we were running any risks of injuring the subjects. In the case of noise, of course, we were trying to stay below a level which would produce hearing damage. In the case of heat, we were trying to stay below a level of what we knew would raise the body temperature very much. Actually, it did rise the internal body temperature a little.

DICKERSON It would seem there might be some optimum value in the curves there, perhaps.

GRETHER I have come to believe that the level of the stresses has a great effect on what happens in such an experiment.

OVERINGTON I would like to draw attention to Figures 4 and 5 of your paper. If the performance during exposure to stress, less the one deviant subject, is studied it can be seen that both noise and heat improve performance. The improvement between vibration and triple stress is virtually the same as the improvement from ambient for noise plus heat. Thus, I see this as a confirmation of stress effects being additive. For pre-exposure and post-exposure the relationship is not as clear although there are some trends. In these two cases there is not really any reason for the effects to be additive as time constants and psychological effects must come into play.

GRETHER You have a good point that I haven't considered. Possibly this could help account for the apparently antagonistic interactions.

COMBINED EFFECTS OF NOISE AND VIBRATION ON COGNITIVE AND PSYCHOMOTOR PERFORMANCE

by

Henry C. Sommer and C. Stanley Harris
Aerospace Medical Research Laboratory
Aerospace Medical Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433
USA

SUMMARY

Five studies on the combined effects of noise and vibration on psychomotor and cognitive performance are reported. Tracking and reaction time tasks were used as measures of psychomotor performance and a short-term memory/subtraction task was used as a measure of cognitive performance. The first study, using tracking performance, suggested an additive effect of noise and vibration on performance, however, this was not confirmed in a second study. Two additional studies conducted with the cognitive task indicated that detrimental effects on this task occurred only when noise and vibration were combined. Further, the effect seemed to be related to frequency of vibration; only 5 Hz - 0.25 g_z vibration combined with noise to produce an adverse effect on the task while the frequencies of 7 Hz - 0.30 g_z, and 11 Hz - 0.50 g_z produced no significant effect on the task even when combined with noise. The final investigation was concerned with the effect combined noise and vibration stress had on cognitive performance as a function of time of day. Although significant effects were obtained, the results indicate that time of day does not appear to be a particularly strong variable.

INTRODUCTION

Crew members are exposed to several stresses simultaneously in most military flight environments. Particularly prominent as sources of such stress are vibrational and acoustical energy. Although research has been conducted to determine the effects of each of these forms of energy on human performance, little information is available on their combined effects. The study of the effects of combined stress on human performance is a comparatively recent effort, and the existing literature has been reviewed by Grether (1). He classified the studies according to the manner in which the stresses interacted to affect performance. Several additive interactions were found but few were found that could be classified as subtractive or synergic. Grether (1) considers this result encouraging, however, he emphasizes that they should not be considered conclusive because of the sparsity of data in the area.

In subsequent studies Grether et al (2, 3) found that vibration alone was as disruptive of tracking performance as combined heat, noise, and vibration. These results are in disagreement with earlier ones obtained by Harris and Shoenberger (4) who found an additive effect of noise and vibration on tracking performance when a higher level of noise was used. There were other differences between the studies besides the absence of heat in the latter study, nevertheless, the difference in results suggests that it is likely to be very difficult to predict the effects on human performance when stresses are combined.

Due to the limited information available on the effects of combined stress on human performance, initially, the extremes of the stress variables should be studied to insure that performance decrements can be measured. Of course, the variable extremes must be carefully chosen to avoid the possibility of physiological damage. Once performance decrements are observed at the extremes, then intensity and duration of the stimuli can be varied in a systematic manner. With this approach it is obvious that performance tasks must be chosen that are sensitive to the stresses being investigated. One such task which is sensitive to vibration is tracking, and consequently this task has been used extensively in investigations of the effects of vibration on human performance (5). Although no conclusive data have been obtained to determine why tracking performance is adversely affected, there is strong evidence that the mechanical action of vibration directly interferes with arm and hand movement (6). In previous combined stress studies (2, 3, 4) tracking was also used as a measure of motor performance since a decrement in performance can be measured with vibration alone and the effect of adding other stressors could then be investigated.

Although a clear understanding of the effects of noise or vibration on intellectual performance is not available, there are a few studies which suggest adverse effects on cognitive tasks. Two tasks which seem to be sensitive to noise are a five choice serial response task (7) and a mental subtraction task (8), while a rolling arithmetic task was found to be sensitive to vibration (9). When investigating cognitive performance in combined noise and vibration stress, a task must be chosen that can be presented without being directly affected by vibration or masked by presentation of noise. The mental subtraction task (8) can be presented so it meets these criteria. This task was originally chosen for study in noise because it required short-term memory as well as mental subtraction. Broadbent (8) points out that one should not assume that immediate memory will be affected by noise when there is no other task to interfere or compete with it; in this case the subtraction was the interfering task.

The results of several studies of the combined effects of noise and vibration on both psychomotor and cognitive performance are summarized in the present paper. In these investigations, a two dimensional compensatory tracking task, always presented in conjunction with two reaction time tasks, was used as a measure of psychomotor performance, and a modified version of the mental subtraction task (8) was used as a measure of cognitive performance. The mental subtraction task was also used to investigate the possibility that performance in a combined stress environment is differentially affected by the phase of the circadian cycle.

PSYCHOMOTOR PERFORMANCE

The combined effects of noise and vibration on tracking and reaction time performance was the first study conducted in our laboratory (4). Only a brief description of the tasks used in this experiment are given in the present paper since they have been described in detail elsewhere (10). Figure 1 shows the subject in place for an experimental run. The tracking task required the subject to keep a dot in the center of a stationary circle by use of a displacement type hand controller mounted at the end of the right arm rest. The circle was 3/8 inch in diameter and was presented in the center of a 5 inch cathode ray tube (CRT) at a viewing distance of approximately 20 inches in front of the seated subject. The dot randomly moved about the screen as determined by horizontal and vertical forcing functions recorded on magnetic tape. The separate forcing functions were composed of random noise filtered to bandpass 0.075 to 0.75 radians per second. The subject's displacement of the control stick was proportional to the velocity of dot movement. The error score for each channel was the integration of the sum of the voltages from both the control stick and program over a 4 minute interval which was the length of a trial used in the experiments.

Figure 1. Experimental arrangement for the tracking and reaction time task.

The reaction time task, response to red lights coming on and green lights going off, was presented in conjunction with tracking. The subject's display panel was located to the left of the CRT and consisted of alternating red and green lights with response buttons located directly below the lights. Three red lights and three green lights were provided. The sequence of lights and time intervals were randomly presented. The time interval between lights varied between 7 and 15 seconds, and a maximum of 6 seconds was allowed before automatic reset. There was an average of 11 changes each of both red and green lights during the 4 minute test period. Since very few errors were made on this task, the measure used was the mean reaction time for each correct response in the 4 minute period. Separate measures were obtained for red and green lights.

Eight male military volunteers participated as subjects in the first experiment. All subjects had performed the task and had been exposed to vibration in several prior experiments. On each of four different days of testing, in the present experiment, one of the following four conditions was presented: (1) 85 dB (dB re 20μ N/m^2) - no vibration, (2) 110 dB - no vibration, (3) 85 dB - 5 Hz vibration at 0.25 g_z, (peak acceleration in the vertical axis) or (4) 110 dB - 5 Hz vibration at 0.25 g_z. Each condition was administered for 19 minutes, four, 4 minute trials plus 1 minute intertrial intervals. In the study, vibration produced significant effects in the analyses of variance for both red ($p < .001$) and green light ($p < .01$) reaction time. Significant effects were also obtained for vibration for horizontal ($p < .05$) and vertical ($p < .001$) tracking. A significant effect was also obtained for noise conditions for vertical tracking ($p < .01$). This effect on vertical tracking was present both with and without vibration, therefore, the detrimental effect of noise was additive to that of vibration when both noise and vibration were presented simultaneously (110 dB and 0.25 g_z vibration at 5 Hz) (see Figure 2). Even though the effect for noise was small relative to the effect due to vibration the question still remains as to why noise only affected vertical tracking and not horizontal tracking or red/green light reaction time. This question can only be answered by additional research.

The same type tracking and reaction time tasks were used in the second study and an attempt was made: (a) to replicate the results of the first study, and (b) to investigate the effects of noise as a function of frequency of vibration. On each of the four testing days two levels of noise were presented in combination with one of the following vibration conditions: (1) no vibration, (2) 5 Hz - 0.25 g_z, (3) 7 Hz - 0.30 g_z, and (4) 11 Hz - 0.50 g_z. The control condition was reduced from the 85 dB noise used in the previous investigation to 60 dB because the higher level of noise was no longer required for masking the sound associated with the reaction time task, and a wider separation of noise intensity would seem to add to the probability of obtaining an effect. Ten male military subjects with prior experience with tracking and vibration exposure participated in this experiment. All conditions were randomly presented.

Only one condition was presented on a day with at least a 24 hour period between exposures. As in the prior investigation, four, 4 minute trials were used with a 1 minute rest between trials for each experimental condition. The only significant effect obtained in this study was for vibration ($p < .01$). A Newman-Keuls test (11) was used to evaluate mean differences. For both noise intensity levels, the means for 5 Hz and 11 Hz vibration conditions were significantly different from the mean for the control condition beyond the .01 level, while 7 Hz vibration differed from the control condition beyond the .05 level. For horizontal tracking, 11 Hz vibration was significantly different from the control ($p < .01$) for both 60 and 110 dB. In addition, 11 Hz differed significantly from 5 Hz and 7 Hz ($p < .01$) for both horizontal and vertical tracking. The mean integrated error for each noise intensity at each vibration level for both horizontal and vertical tracking is presented in figure 3. The greatest increase in tracking error occurred for the 11 Hz vibration condition. The reason for this difference can be attributed to the fact that acceleration level was not kept constant, a much higher g level was presented at 11 Hz than at the other frequencies of 5 Hz and 7 Hz. It was felt that a higher g level was necessary to produce a significant effect on tracking performance at 11 Hz, however, the level chosen was apparently too high which obscured any possible differential effect of frequency. This does not, however, obscure the main intent of the present paper which was to examine a differential interaction of frequency of vibration with noise intensity. Furthermore, the results of this study can be compared with those of the previous study (4) since the 5 Hz vibration was presented at the same acceleration level in both studies. Unlike the first study, the subsequent study did not show any significant effect of noise on the vertical part of the tracking task. Similarly, there was no significant effect for trials, and vibration did not produce a significant increase in reaction time to red and green lights. In agreement with the previous study, 5 Hz vibration had more detrimental effect on vertical tracking than on horizontal tracking, however, the effect of 5 Hz vibration on horizontal tracking was statistically significant in the previous study but it was not in the present study.

Aside from the differences in experimental design and the slightly lower noise intensity used in the present study, the greatest difference between studies was in the performance level of the subjects. The subjects used in the first study were extremely well trained and very proficient in performing the task as was evidenced by the small within and between subject variability. Although identical tasks were used in both studies, the average reaction time for the control condition in the latter study was approximately 30% longer than in the prior study. Similarly, tracking performance was better in the first study. Since the effect of noise was very small relatively to the effect produced by vibration, subjects may have to be very well trained on the task so small effects are not masked by subject variability. There is also the possibility that the subjects had greater ability in the first study and the difference was not just one of training. In this case, noise may have a greater effect on subjects with high ability and less or no effect on subjects of low ability. Also, one should not forget that the noise levels in the two experiments were different and this may be of importance.

Additional research is planned in which the same levels of noise will be used as in the latter study, however, vibration will be presented at a constant acceleration level across vibration frequency, and the subjects will be trained on the tasks until their performance reaches a stable baseline.

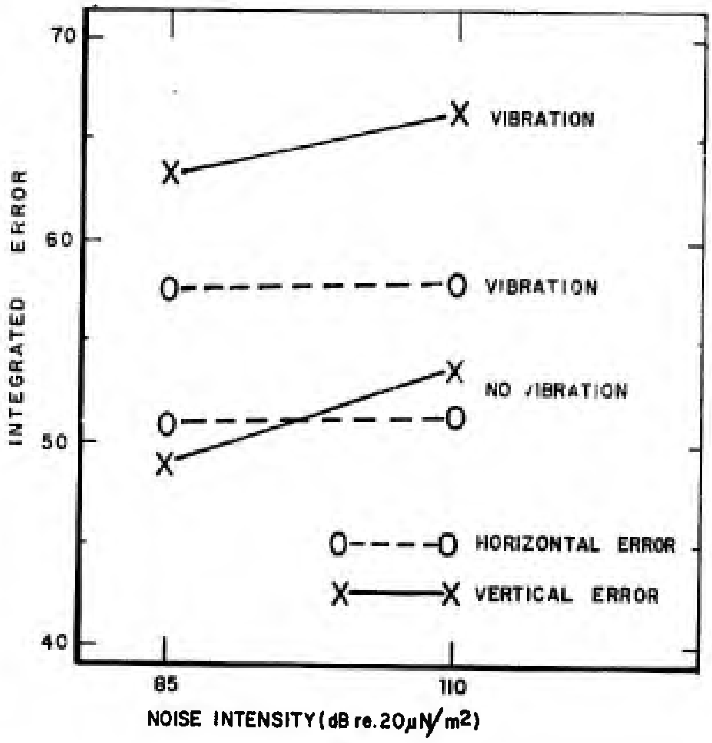

Figure 2. Mean integrated error for horizontal and vertical tracking at 85 dB and 110 dB both with and without vibration.

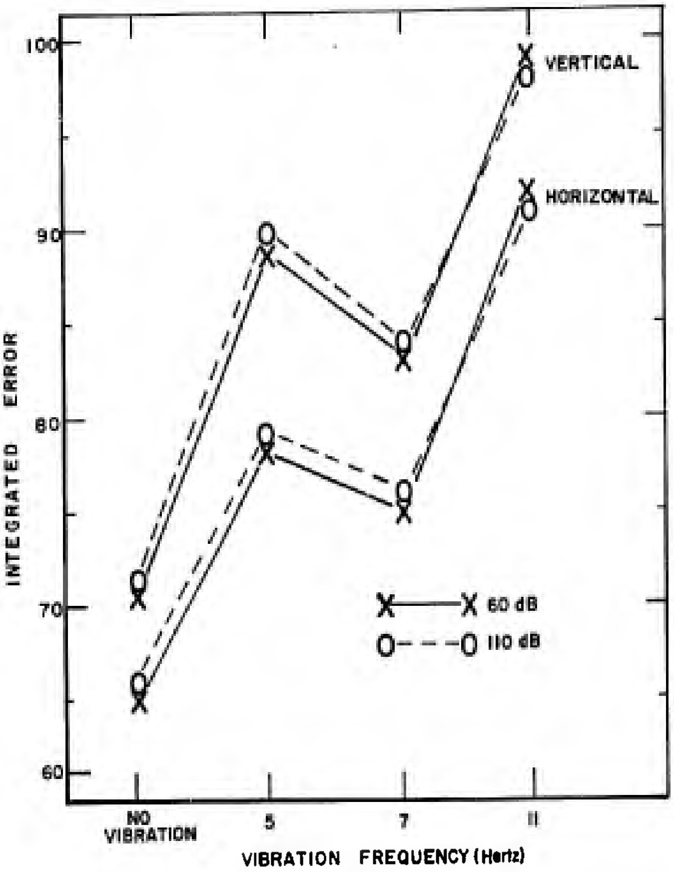

Figure 3. Mean integrated error for vertical and horizontal tracking at 60 dB and 110 dB for each vibration condition.

COGNITIVE PERFORMANCE

Two experiments were conducted to determine the effects of combined noise and vibration stress on cognitive performance. In both experiments, the task used for measuring performance was a modified version of a mental subtraction task used by Broadbent (8). Figure 4 shows the experimental arrangement for the cognitive task. A six digit number was projected on a screen mounted approximately 6 feet in front of the subject. The projected digits were large enough to ensure clear visibility during vibration. When the subject had memorized the six digit number, he activated the slide projector by a hand held switch. This removed the six digit number and projected a four digit number. The subject's task was to subtract the four digit number from the six digit number he had previously memorized. When the subject was satisfied that he knew the answer, he again pushed the hand held switch which caused the screen to go blank. During this time he announced the answer into a microphone mounted on the head set. The verbal response was monitored and recorded by the experimenter who had an answer sheet in front of him so he could observe the correct number at the same time the answer was given by the subject. When the subject was ready for the next series of digits, he again activated the switch and another six digit number was presented. The procedure on this task is depicted in figure 5. This procedure was repeated 18 times in each testing session in the first experiment and 24 times in the second experiment. Subjects proceeded at their own rate with no time limit imposed. The switch response was recorded on a chart recorder. Three measures were obtained for analysis; memorization time, calculation time, and number of correct answers. A trial was based on the mean performance on six problems. Therefore, within a testing session there were three trials in the first experiment and four trials in the second experiment.

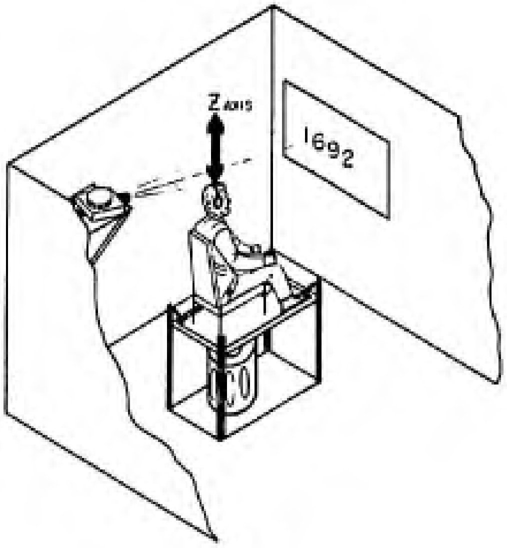

Figure 4. Experimental arrangement for the cognitive task.

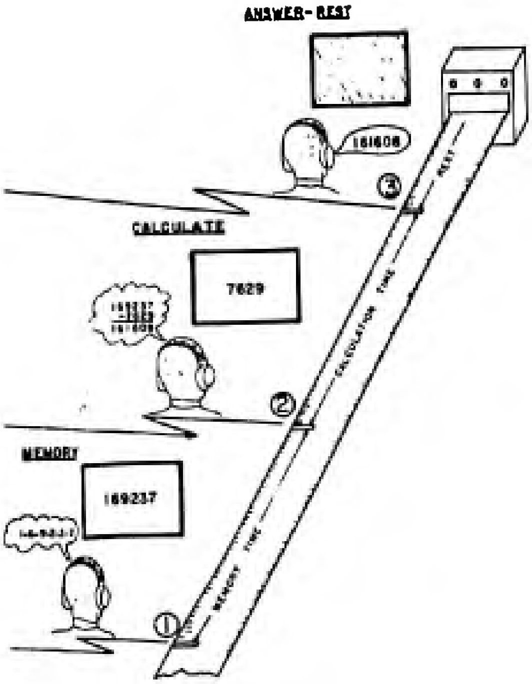

Figure 5. Schematic representation of performance on the mental subtraction task.

All subjects used in experiment 1 had participated in previous experiments and had performed 18 problems from the task on each of five different days. All student subjects had experienced noise intensities as high as were used in the present experiment, and the vibration panel subjects had extensive experience with noise and vibration exposures at levels comparable to those used in the present study. Thirty student subjects were given five days of practice on the task and also tested on the preliminary day of the experiment proper. On the basis of the scores obtained on the last set of 18 problems on the preliminary day, ten of these subjects were matched on an individual basis to the preliminary scores obtained from the 10 vibration panel subjects. The matched score was the number of problems correctly completed on the second set of 18 problems during the preliminary test day. The other 20 subjects were dropped at this point in the experiment. Thirty student subjects were tested before "matches" with the scores of the vibration panel subjects were obtained. This procedure does not make the groups truly comparable. The average age for the vibration panel subjects was higher than for the college students. All but one of the vibration panel subjects were college graduates, and their scores as a group, in terms of number correctly completed, were higher than for the total group of college students. Nevertheless, 10 college student subjects were tested whose performance was comparable on an individual basis to the performance of the 10 vibration panel subjects. This procedure was necessary since only vibration panel subjects can be exposed to vibration, and only ten of these subjects were available for participation in the study. Subjects who took part in the experiment proper were tested on five consecutive days. The first day was a practice session in which they were given instructions (actually reviewed since all subjects had previously performed the task) and briefly exposed to each of the experimental conditions subsequently presented on the test days. Two series of slides, each consisting of 18 calculations, were then presented. Subjects were told that speed and accuracy were important but to take sufficient time to ensure that they obtained the correct answers. Both groups received the noise intensities of 80 dB, 90 dB, 100 dB, and 110 dB. The college students received only noise while the vibration panel subjects received noise plus vibration. For the panel subjects, the same frequency and intensity of vibration, 5 Hz at 0.25 g_z accompanied every noise exposure. The experimental conditions were presented in a different random order to each subject on the four experimental testing days. Only one condition was presented on each day and 18 problems of the mental subtraction task were presented. The exposure duration was determined by the length of time required by the subject to complete all 18 problems. Six different sets of 18 problems were used in the experiment, and each subject was assigned a different random order of presentation. The problems used were not the same as those used in the week of preliminary training.

In experiment 2, the same 10 vibration panel subjects who participated in experiment 1 were used. It would have been preferable in this part of the study to use two groups of subjects, however, this was not possible for two reasons. First, vibration can only be presented to physically qualified volunteer members of the vibration panel, therefore, additional subjects could not be obtained from the college student population. Second, due to the small number of subjects available on the vibration panel, only one group of these subjects could be obtained. Therefore, each subject was tested during all experimental conditions.

Experiment 2 was divided into two successive parts. All subjects were tested for five consecutive days in part 1, and after an interval of 1 to 2 weeks, they were brought back to the laboratory and tested on 5 consecutive days in part 2. The first day in each experiment was a practice session and subjects performed two sets of slides consisting of 24 problems in each set. Twenty-four problems were used instead of 18 as used in the first experiment. Because of the increased time required for the performance of the additional 6 problems, 107 dB noise was presented instead of 110 dB in part 2. This 3 dB noise reduction was necessary to assure no threat of hearing damage. Subjects were presented the following conditions: (1) 80 dB - no vibration, (2) 80 dB - vibration at 5 Hz - 0.25 g_z, (3) 80 dB - vibration at 7 Hz - 0.30 g_z and (4) 80 dB - vibration at 11 Hz - 0.50 g_z. The experimental conditions were presented in a different random order to each subject on the four experimental days. Only one condition was presented on each day and 24 problems of the mental subtraction task were presented. In part 2, exactly the same conditions and procedures were used as in part 1 with the exception that 107 dB noise was presented with each condition rather than 80 dB noise. Different problems on the task were used in part 1 and 2. Within each part of the experiment, each subject was presented a different random order of the lists.

An analysis of variance was calculated for each of the three experimental measures, memory time, calculation time, and number of correct answers obtained in experiment 1. No significant effects were obtained in the analysis of variance for memory time or for calculation time. Significant effects for the Noise x Vibration interaction ($p < .05$), and for Trials ($p < .05$) were obtained in the analysis of variance for the number of correct answers. As seen in figure 6, the mean number of correct answers for vibration plus noise at 100 dB and 110 dB was less than those obtained for the same noise conditions without vibration. A <u>t</u> test (11) was used to evaluate the difference between means at each noise level and only the difference between means at the 110 dB level was found to be significant ($p < .05$). The superior performance of the noise plus vibration group at the 80 dB level, although not statistically significant, supports an interpretation of the results in terms of arousal theory.

Subjects became less accurate across the three trials and there was the suggestion that trials' effect was greater for the combined noise and vibration group than for the noise along group (see figure 7). However, this differential effect of trials was not supported statistically.

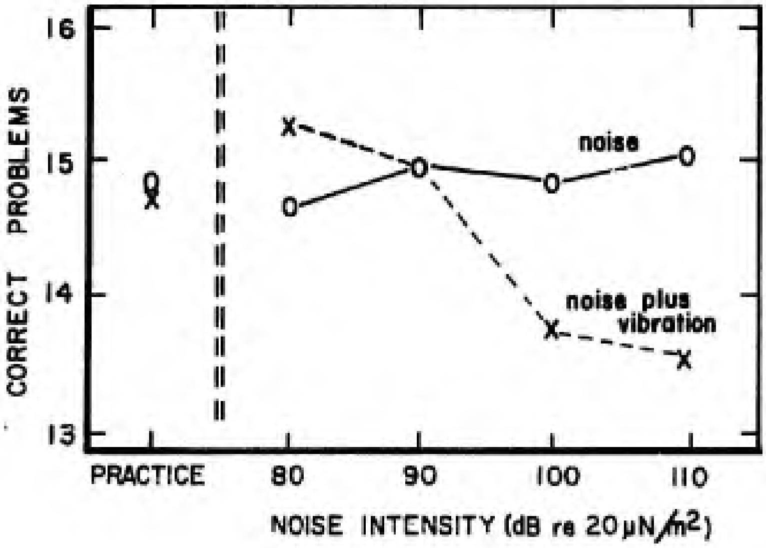

Figure 6. Mean number of correct problems for noise exposure group and noise plus vibration exposure group.

In experiment 2 analyses of variance were calculated on all measures obtained in part 1 and part 2. A total of six analyses were performed. No significant effects were obtained in any of the analyses conducted on memory time, calculation time, or for number of correct answers. However, in the analysis for the number of correct answers during part 2, the effect for stress conditions (frequency of vibration) approached significance ($p < .10$). Figure 8 presents the results for the mean number of correct problems obtained in both parts of the experiment. A direct comparison cannot be made of the effect of adding a more intense level of noise to the constant vibration parameters, since the same subjects were tested successively in the two parts of the experiment and they became more accurate in their performance from the first part to the second as indicated by the mean number correct during the practice periods (see figure 8). Nevertheless, there is evidence that task performance is more sensitive to vibration combined with 107 dB noise at 5 Hz (in addition to the fact that a lower peak g level was used at 5 Hz) than at 7 Hz

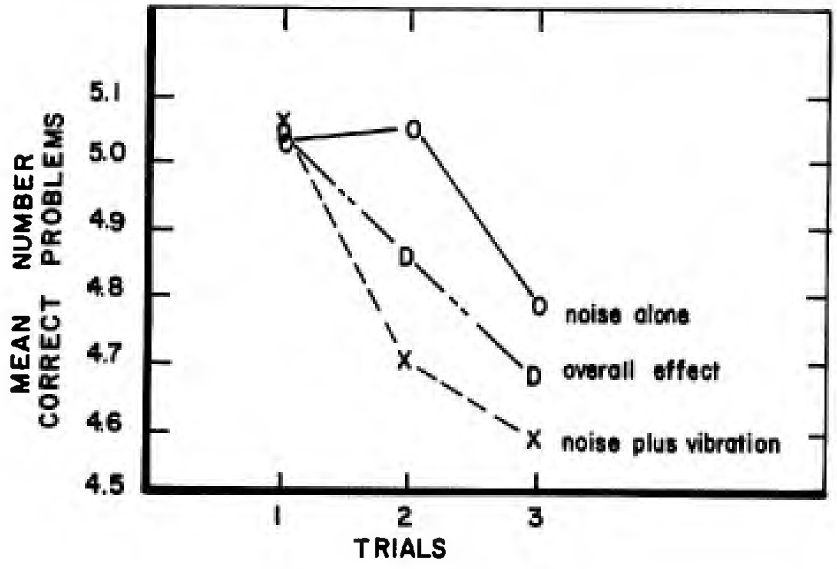

Figure 7. Trial means for overall effect and for the noise exposure group and noise plus vibration exposure group.

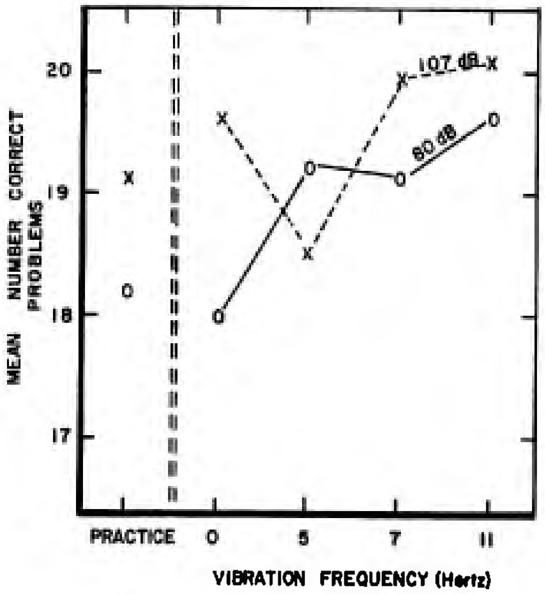

Figure 8. Mean number of correct problems for vibration - 80 dB exposure and vibration - 107 dB exposure.

and 11 Hz. This evidence was obtained by comparing each subject's performance in each of the conditions with low level noise with the comparable conditions using high level noise, i.e., a difference score was computed for each subject for each vibration condition. An analysis of variance conducted on these difference scores for number of correct problems yielded a significant effect for vibration frequency ($p < .01$). A t test revealed that the mean difference score at 5 Hz was significantly smaller (a constant was added to all scores to eliminate negative numbers) than the mean scores obtained for the control ($p < .01$), 7 Hz ($p < .05$), and 11 Hz ($p < .05$). The latter three conditions did not differ significantly. This result can be understood more clearly by referring to figure 8 where the mean number of correct problems for all conditions are plotted. The means for control, 7 Hz, and 11 Hz conditions show an increase in accuracy when the noise intensity was increased from 80 to 107 dB, while the mean for 5 Hz showed a decrease in accuracy.

The results of the first experiment indicated that 110 dB noise combined with 5 Hz vibration produced a significant reduction in the number correctly completed on the mental subtraction task, while the same level of vibration combined with lower intensities of noise (80 dB, 90 dB, and 100 dB) produced no significant effects. The task did not reveal any significant effects of noise alone contrary to the results previously obtained by Broadbent (8). Broadbent (8) presented 30 problems of the task to his subjects and found that a significant difference in mean calculation time occurred on the last ten problems between a group tested during 70 dB noise and another group tested during 100 dB noise. In the present study fewer problems were presented to the subjects but a higher intensity of noise was used. Further, the significant effect obtained for combined noise and vibration in the present study was for number correctly completed and not for calculation time. This difference in results cannot be explained at present.

In the second experiment, an attempt was made to replicate the adverse effect demonstrated with 110 dB noise combined with the 5 Hz vibration in experiment 1. In addition, the effect of vibration frequency was examined to determine if the same frequency pattern sensitivity would occur for performance on the mental subtraction task as has been previously demonstrated for tracking performance (6) and for subjective judgments (12). Judging from the results of experiment 1, we had expected to obtain a significant effect for stress conditions (frequency of vibration) in the second part of experiment 2. In particular, the difference between the no vibration - 107 dB noise condition and the 5 Hz vibration - 107 dB noise condition was expected to differ significantly. There are a number of factors that could account for the failure to find statistical support for the results of experiment 1, such as, the change in experimental design, the lower noise level used in experiment 2 (107 dB instead of 110 dB), and the increase in the number of problems presented to the subjects. There is also the possibility that because of their extensive experience with task and stresses the subjects were adapting.

Because of these complicating factors, conclusions derived from the present study must be considered tentative. Nevertheless, 0.25 g_z vibration at 5 Hz combined with 110 dB noise for short time periods is probably close to the minimum level, at this frequency, that produces a decrement on the mental subtraction task. Also, the results of the analysis of variance performed on the difference scores in experiment 2, strongly suggest that 5 Hz vibration is a more sensitive frequency for mental subtraction performance than the frequencies of 7 Hz and 11 Hz when all three frequencies are presented in conjunction with high intensity noise. This agrees with the pattern of sensitivity found for subjective judgments and tracking performance. Further, it seems clear that a lower intensity of vibration at all three frequencies is necessary to produce a decrement in tracking performance (6) than is necessary to produce a decrement on the mental subtraction task. Finally, high intensity noise and vibration at 5 Hz seem to combine to produce a greater decrement in performance than either stressor alone.

The final study to be reported used the memory/subtraction task to investigate the possibility that performance in a combined stress environment may be differentially affected by the phase of the circadian cycle. Subjects were tested on five consecutive days. The first day was a practice session in which subjects were given instructions and briefly exposed to each of the experimental conditions subsequently presented on the test days. A complete series of slides, consisting of 18 calculations were then presented. Subjects were told that both speed and accuracy were important but to take sufficient time to ensure that they obtained the correct answer. The experimental conditions of (1) 85 dB noise - no vibration, presented at 6 AM, (2) 85 dB noise - no vibration presented at 3 PM, (3) 110 dB noise - 5 Hz at 0.25 g_z, presented at 6 AM and (4) 110 dB noise - 5 Hz at 0.25 g_z, presented at 3 PM were experienced by each subject in a different random order on the four experimental testing days. The exposure duration depended on the length of time it took the subject to complete all 18 problems. The average time was approximately 20 minutes.

An analysis of variance for a three-way treatment by subject design was calculated for each of the three measures obtained in the experiment. No significant effects were obtained in either of the analyses for memory time or calculation time. The most interesting effect obtained in this experiment was the Time of Day x Stress interaction for the number of correct answers. This interaction can be understood by referring to figure 9. In this figure the mean number of correct problems are plotted for each of the four conditions used in the experiment. The means obtained at 6 AM for stress and no stress conditions were 12.3 and 12.6 respectively, while at 3 PM the means were 11.4 and 13.4 for the same conditions. The mean differences among the four conditions were analyzed by use of t tests, and only the difference between the stress and no stress conditions obtained at 3 PM was found to be significant ($p < .05$). Therefore, the Time of Day x Stress interaction was due to both an improvement in performance at 3 PM with no stress, and a decrement at 3 PM with stress. Since the effect obtained at 3 PM was small and no significant difference was found between 6 AM and 3 PM for either stress or no stress, time of day does not appear to be a particularly strong variable for this task. Additional research is contemplated which will investigate the effect of time of day on the psychomotor task.

DISCUSSION

The two studies conducted on the effects of combined noise and vibration on psychomotor performance did not lead to encouraging results. The effect of noise was additive to the effect of vibration for vertical tracking scores in the first experiment. In the second experiment no effect was obtained for noise and less sensitivity was demonstrated for 5 Hz vibration. The change in experimental design and slight changes in procedure from the first to second experiment led to different results. The difference in the level of training or in the initial ability of the subjects will be investigated in future experiments.

The results obtained using the short-term memory/subtraction task were more consistent than those obtained using the psychomotor task. These results seem genuine since significant effects were demonstrated for combined noise-vibration stress in two experiments, and approached significance in the third ($p < .10$). The fact that the same measure was affected each time also adds credibility to these results. A small reduction was found in the number of problems correctly completed when both noise and vibration were combined. Two factors of particular interest concerning the cognitive task were (a) a high level of noise (110 dB) had to be combined with 5 Hz vibration to obtain a significant effect, and (b) the significant effect was obtained on the number of correct problems and not on calculation time as expected from Broadbent's experiment (8). Since accuracy of response was the only measure affected by the combined noise and vibration, a task that is presented for a fixed period of time should show more sensitivity.

In an area where research is just beginning ambiguous results are not surprising. There can be no argument that there are many variables that are not fully understood, and with more research, results with greater generality will be obtained. This same problem exists with single stresses such as noise, which has been studied for a long period of time, and the results are still ambiguous. There are probably a number of things that must be recognized if a systematic body of knowledge on the effects of stress on human performance is to be obtained. First, there must be an improvement in the quality of research conducted. Aside from improvements in procedures, instructions, and experimental designs, a great deal of the ambiguity that exists in the environmental stress area, can be cleared up by simply using more subjects in the experiment, and/or by increasing the length of testing time both by giving more preliminary training to the subjects, and by testing for a longer period of time within the experimental sessions. Some of the ambiguity of the current contribution can be removed by this approach.

Next, it will be necessary to recognize that there is no such thing as the interactive effect of stresses on performance. The interaction will change as a function of many instructional, situational, task, and training variables.

Finally, at some point in the process of understanding the effects of combined stress on performance, attention should be given to individual differences. Perhaps by the use of proper experimental methodology, meaningful statements can be made concerning the data obtained from randomly chosen groups. In other words, all subjects may be affected in the same way or direction. With extreme environmental stress, such a group response would seem reasonable, however, Appley and Trumbull (13) state: ". . . certain universally adequate stimuli may be expected to lead to stress more rapidly than others - as, for example, cutting off the air supply. This should lead to a stress state in all persons, with little variation in the rate of its development. However, any less severe stimulation - and particularly where the effectiveness of the stimulation is dependent on prior conditioning (as in the case of social stimuli) - will give rise to response patterns that vary greatly from person to person and may induce anxiety of stress much more rapidly in one person than another." Perhaps attention will have to be given to attitudinal and personality variables of the subjects.

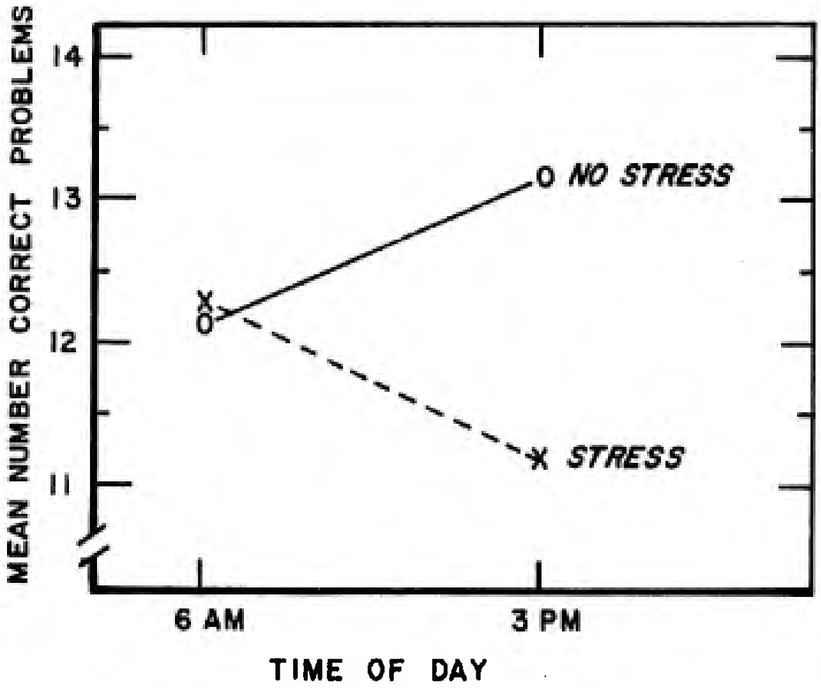

Figure 9. Mean number of correct problems for conditions of stress and no stress according to time of day of testing.

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The research reported in this paper was conducted by personnel of the Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. It has been identified by the Aerospace Medical Research Laboratory as AMRL-TR-71-115. Further reproduction is authorized to satisfy needs of the US Government.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 80-33.

Some Critical Comments on the Measurement of In-Flight Strains

W. HOFFELT, Dipl.Psych., and K. GERBERT, PhD,
German Air Force Institute of Aviation Medicine,
808 Fürstenfeldbruck, Fliegerhorst, Germany

Summary

The German Air Force Institute of Aviation Medicine has been asked to give an expert opinion on the justification of different flying pay in the German Air Force. The Institute therefore plans to objectify the extent of flying stress.
It is discussed what ways and means aviation physicians and aviation psychologists have at their disposal to clarify the question of the overall stress imposed on flying personnel. Methodical difficulties are presented which result especially in the measurement of psychophysiological reactions to flying stress. The authors are of the opinion, that at the present state of research psychological questionnaire - and evaluation techniques are the only means which offer partial assessment possibilities concerning the problem of flying stress.

Some time ago, the German Air Force Institute of Aviation Medicine, was charged to give an expert opinion relating to the differing flying pay between jet, propeller and helicopter pilots in the German Air Force. This request was prompted by complaints of propeller and helicopter units, which felt their flying pay to be injust as compared to the more liberal payment of jet-pilots.

In order to ward off complaints of this nature in the future, it was decided to investigate the justification of the complaints raised on a scientific basis, i.e. through an objective assessment of strains, to which the 3 pilot groups are subjected to on the average. Being true children of our era, we tried at first to reach our goal mainly by means of telemetric transmission of physiological parameters. After a certain time of diligent experimentation, however, our opinion concerning the methodological part of the problem changed considerably. Meanwhile multiple deliberations have caused us to lose hope to quantify the stress,to which the flying man is exposed, with the aid of present day psychophysical measuring methods. We are rather of the opinion, that according to the present state of science, psychology will help us more than physiology to obtain useful data, if at all.

I shall try to explain our reasons for this assumption. The cardinal problem to be tackled in stress investigations is the question concerning quality and intensity of the correlation between the stressing stimulus and the stress reaction. To solve this problem respectively bringing it closer to a solution, experiments were chiefly performed with that parameter which seemed to be the easiest one to manipulate, namely the stimulus. In literature we find a multitude of extremely differing stress situations concerning the subject of stress. They extend from extreme life threatening situations to harmless experiences, as for example slight galvanic skin stimulations.
While it seems comparatively simple to establish a relationship between the stimulus and the ensuing reactions in extreme situations, in which the subject feels threatened or in which his physical integrity is actually endangered, the methodical difficulties will accumulate the more if one proceeds in the direction of the other extreme, where he is confronted with very weak stimuli. At this point, it is immaterial, under which aspect the problem is considered, under the aspect of the stimulus or that of reaction. If one moves along the continuum from the threatening stimulus conditions, which surpass the physiological regulatory possibilities, in the direction towards the weak ones, a point will be reached sooner or later where some subjects will no longer show any measurable reactions, whereas other individuals will indicate through their overt reaction, that they feel the situation to be stressful. It is at this point at the latest that it becomes clear, that a mechanistic stimulus-reaction way of thinking in psychophysiology does not help, but that beyond measurement of stimulus intensities special attention must be devoted to stimulus quality with its special importance for the individual. This applies in particular to those stimuli, which are not immediately experienced as threatening life and limb. Comparable with the key-stimuli of behaviour research the individual does not generally react to every stimulus but selectively to those stimulus configurations for which he has developed a special sensitivity. In the human sphere this sensitivity does not so much originate in genetically fixed S-R-patterns as in an animal, but more so in certain personality factors which intervene in the perception process by raising the perceptive and reactive readiness and preparedness for certain stimuli and lowering it for others.
In order to be able to understand why one given individuum reacts violently to a presented stimulus quality and another one not at all, it is necessary to have a knowledge of his personality structure, the experiences he has made, his motives, his inner values. These determinants are the key to an understanding and prediction of stress reactions because they open an immediate access to the manner in which the given situation is appraised and what measures are taken to cope with it psychically. The physiological and verbal reactions may be thought of as being the visible results of this process.

In addition to these intraindividual factors, the influence of extraindividual factors may not be overestimated. In this context we could in particular think of the influence of related persons of the individuum or of social and cultural determinants, which may subjectively aggravate or ease objectively given situations.
Where it is already difficult - not to say impossible - to obtain an interindividually valid pattern to a single known stimulus, one may assume much greater problems with increasing stimulus complexity. If one does not want to lose contact with the real life situations, one must deal with complex stimulus configurations - if one likes to or not. Thus, it is for example not sufficient to attempt to deduce the overall stressing character of a flying situation, in which we are interested, from the presence of a threat, whatever the definition may be. The pilot is without doubt, not only stressed by the awareness of an anticipated stress, but also by the required mental performance

and to a certain degree by the physical environment, in which he must perform. In contrast to most laboratory experiments the pilot in the real situation is not only exposed to one single stressor but to a number of non-standardized simultaneously effective stressors, which generally lead to very complex stress reactions. The summation of heterogeneous stimuli and the complexity of reactions caused by them make a quantifiyng assessment of the overall stress extremely difficult and a physiological differentiation between stress reactions and their association to certain stressors illusory.

The impossibility to sufficiently standardize a flying situation is of course only one handicap in in-flight studies. A second one, not less important, results from the difficulties to assess with adequate accuracy the performance potential of the pilot in a dynamic flight situation, which is a decisive criterion for the onset of stress reactions. The common method to rate the flying performance during single flight phases and interpret them as overall performance, is unsatisfactory in our opinion, because it does not consider the ease with which this performance is accomplished and consequently the available reserve capacity for additional stress.
What is difficult to grasp in real situations may be easier in the laboratory situation where standardization and therefore control is no problem. What can we learn from laboratory experiments in this context?

In an average laboratory experiment the subject is exposed to a stimulus, which in the opinion of the examiner constitutes a stressor to the subject. With the aid of mostly very complex apparatus it is then attempted to correlate the values at rest with the stimulus-induced magnitude of reaction, and with the time measures after the cessation of the stimulus. Even though many investigations report significant correlations between stimulus and reaction, it is one of the most surprising discoveries when comparing relevant literature to find a lack of consistency between the various reactions on one hand and the stimuli on the other hand. Many authors explain the low intra- and interindividual covariance of physiological variables with some systematic errors, which may be traced back to primarily three causes:

1. The law of initial value

2. The individual reaction specifity and

3. The low stability of physiological parameters

Ref. 1: In 1931 WILDER has already formulated a law, stating a negative correlation between the initial value and the magnitude of reaction. He claims that the sensitivity for exciting stimuli is the lower respectively the response on inhibiting stimuli the higher, the stronger the arousal of the vegetative system already is. Therefore a systematic error is introduced if one takes the magnitude of the change score D_i as an expression of the individual reactivity and calculates it from the difference between initial value and post stimulus value without appropriate statistical correction, because D_i is significantly influenced by the respective initial value. There are of course some attempts to eliminate this error. First of all, mention should be made of the autonomic lability score (ALS) methods by LACEY and by BENJAMIN. They can, however, frequently not be applied because the statistical prerequisites are lacking.

Ref. 2: Frequently very low correlations of physiological measurements from various functional areas on many persons are reported. There have been many studies to clarify these disappointing results. LACEY provides an important argument. According to his principle of reaction specifity psychophysical stess will not lead to a uniform switch-over of the VNS. Rather we may observe individually specific reaction patterns which remain rather constant also during various stimulus situations in an individuum. Subjects may indeed show constantly prominent reactions in one organic system, whereas they are constantly hyporeactive in another one.

Ref. 3: The meaningful interpretation of physiological measurements is based on the assumption that such measurements can be done in reliable manner. Even though physiopolygraphs normally guarantee a relatively high formal measuring accuracy, the measured values nevertheless escape reliable registration, more than is convenient. The reasons for this fact are on one hand errors inherent in the methods and on the other hand the natural variability, i.e. the instability of functions. Uncontrollable disturbances, interactions between examiner and subject, reduce the reliability coefficients just as much as momentary endogenously caused oscillations or prolonged reversible fluctuations or irreversible variations. The difficulties which one encounters in the physiological measurement of what is collectively termed stress, are not exhausted with this enumeration.
The following will support this opinion.
Physiological measures are not static values, as already pointed out. They are influenced by numerous exogenous and endogenous factors which exert a changing effect on them. Thus, any physiological measurement presents a rather arbitrary sample taken from a dynamic process, which at best is useful to indicate a momentary state. Since it only describes a transitional phase, it is difficult to attribute representativity for a long-term internal state to it. If one desires more than a more or less arbitrary momentous picture, one is forced to perform time analyses, which may lead to relevant statements in individual cases, if one knows the individual range of variation and frequency of variation. They will, however, not permit individual valid predictions. The indicated metric problems arising from the contrast between inter- and intra-individual correlations, from the dependency of reaction magnitude on the initial value, from the instability of the physiological parameter and from individual- and stimulus-specific reaction behaviour, can be bypassed with the aid of appropriate psychological methods.

In addition to the proved methods of task descriptions and task analyses, with the aid of which we can approximately estimate the objective amount of the stress posed by working situations, we are of the opinion, that interviews with pilots are a supplementary and under certain circumstances even a replacing method. In context with stress problems in flying personnel we consider it as the method of choice if one starts off from the assumption that a knowledge, for instance, about pulse rate in a given work situation seems to be less significant under the aspect of job satisfaction and effectiveness than a knowledge about his subjective assessment, which is attached to a stress situation in the experience on part of the acting man. Information concerning the quality and quantity of an objectively given strain and the reaction caused by it are characterized by a certain academic noncommittance as long as one does not know if the psychic system is effected by it at all, and if so, how an individuum experiences and processes the internal psychic unbalance provoked by the stimulus conditions. We are aware of the fact, that by using this approach we are proceeding in a different level of analysis and are excluding an important aspect of the problem, namely the psychological side of it. We are, however, of the opinion that the scientific significance of the physiological measurements can not be found in them per se, but that they finally serve the same goal, i.e. the psychic state of the stressed individual whose immediate obvious expression are the physiological reactions and the performance behaviour. We do not confine ourselves to the portion of psychic experience because we think it to be the indicator of stress, but because of the above mentioned difficulties which at the present are still opposed to an evaluation of the psychical stress correlates. The scientific justification of our approach lies in the fact, that the physiological reaction values and the information gained through psychological inquiries, have to be considered as an expression of the total process as well as ~~in~~ the efficiency of the interview technique as a measuring tool for the practical work.

Just a few words concerning this aspect.

Depending on the degree of standardization of the inquiry, the interviewer has extensive, limited or no degreesof freedom at all. There is an abundance of literature dealing with the advantages and disadvantages of the different techniques. We are not trying to give a synopsis at this time, but shall merely talk about the so-called standardized interview which in our opinion is the best one for our purpose.
The most essential arguments in favor of an interview technique in which the formulation of question and their sequence has been defined through a standardized questionnaire down to the last detail, lie in the strikingly simple handling of the single findings and in the almost complete elimination of the possibility for the interviewer or interviewee to bias the results. The latter deserves special mentioning, since it has been shown repeatedly that interview results may be influenced more or less strongly by even slight variations of the text, the sequence of questions or other aspects of the test situations. This phenomenon may be explained psychologically in that the behaviour of the respondent is not only a function of his individuality but also a function of the inquiry situation, of the questions asked and of the context in which they appear. For reasons of controlling the test situation it seems therefore advisable to keep as many aspects in a questionnaire-type assessment as possible constant in order to be able to trace back occuring intra- and interindividual differences in the answers to the individual character of personality variables.

The idea, that the text of the questions determines the answers, occasionally led to a demand for quite open formulations of questions leaving the subject much freedom in order to avoid any kind of influence on him. This, at first glance, seems to make sense. However, aside from the evaluation difficulties when applying open questions, this deliberation does not consider one essential draw back of this type of questions: open questions are not to the point, i.e. one obtains only more or less accidental answers to the core of a question to be actually clarified. Upon comparison, the closed question with its clearness, which makes an answer easy, its simple handling, the possibility of a simple and accurate recording, coding and evaluation are ideal to a high degree. This applies to the most simple form of the yes-no type as well as to the so-called graduated question, in which the respondent marks his answers on a graphical or verbal continuum, and also to the catalogue question permitting more than one answer.
Standardized questions are, however, not without shortcomings. For instance they share the difficulty of reliability and validity determination with the open and semi-structured types of questions. Reliability is difficult to determine inasmuch as neither split-half methods, nor parallel testing methods nor interitem consistency determination may be applied, but only the retest method, the application of which is particularly problematic in this case. While in questions being repeated after short-time learning and memory effects may easily lead to an overestimation of reliability, the time interval on the other hand must not be too long, because personality and/or attitude changes meanwhile may have negative effects on the retest coefficients. It may be expected that these changes weigh the more in a repeated interview, the greater the measuring accuracy of the questionnaire.
Generally it may be pointed out that reliability may be improved by considering the formal and also the content criteria of the questions. Under formal aspects, for example, a high degree of standardization and as many questions as possible concerning the same subjects are considered as advantageous. Under the content aspect, for instance, simple fact finding questions and positive experiences are answered more reliable than questions concerning opinions or those concerning unpleasant experiences.
The validity of the interview results is found by correlating them with an independent external criterion, as is the case in validity determinations in other techniques. Because much of the information, gained in an interview, can only be obtained through this method, independent validity criteria are only available in such cases where controllable statements (age, socio-economic status, origin, diseases etc.) are made. But even with such data the correctness of the statement often depends on certain imponderables such as social desirability, aspects of prestige, psychological defence machanism a.s.o., thus. making validity dependent on the subject in question. One should, however, not overestimate the influence of subjective bias. In order to bias effectively, the subject first of all must have a knowledge about the optimal strenght of the traits in question, ways of behaviour, attitudes and so on.
Socially viewed the tendency to select extreme positions by no means always results in the most favourable answer when attempting to bias.Because we are not only inquiring members of the group to be inquired, but additionally experts no longer belonging to this group but knowing exactly

the tasks to be investigated, as well as other groups with related tasks, we might thus effectively counteract any attempt to bias.

The weak points of the questioning techniques mentioned briefly can by no means be overlooked. The difficulties to determine the reliability and validity leave a feeling of uncertainty when dealing with such techniques. Nevertheless, we think it is too early to put them to the files for we have no better methods for the time being which would serve a purpose as ours so adequately. Even though reliability and validity coefficients do not reach the required level, we should welcome interview techniques as long as we gain information through them which we can not yet gain with the aid of psychophysiological methods.

In concluding may I say, that at the time this paper went to print, the processing of the pilots' interviews had not yet progressed to a point permitting final evaluation. We will, however, report on the investigations and their results in a separate paper as soon as possible.

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EMOTIONAL AND CARDIOVASCULAR STRESSES OF CENTRIFUGATION: EFFECT OF BETA RECEPTOR BLOCKADE ON HEART RATE RESPONSE

by

D H Glaister, M F Allnutt, M H Harrison and P Fennessy
Royal Air Force Institute of Aviation Medicine
Farnborough, Hampshire, England

SUMMARY

Twenty four subjects were used in a double blind trial to investigate the effect of beta adrenergic blockade on the heart rate response to acceleration. Oxprenolol, 0.2 mg/kg body weight, or saline placebo, was injected in paired trials, and subjects then performed a tracking task and submitted to three centrifuge runs. Heart rate and blood pressure were monitored continuously. Oxprenolol reduced resting heart rate, and abolished a steady increase in base line heart rate seen in placebo experiments, and attributed to activation of the adrenal medulla. Tachycardia in response to $+2G_z$ acceleration was prevented by beta blockade, except in a group of six subjects experiencing their first ever centrifuge ride. Heart rates at $+3G_z$ were lowered by oxprenolol, the persistent tachycardia being attributed to a baroreceptor reflex mediated through a reduction in vagal tone. Pulse pressure was reduced by oxprenolol, especially during $+3G_z$ acceleration, an effect attributed to a reduction in cardiac output secondary to a fall in heart rate. Greyout tolerance was unaffected by beta blockade, but a small and unexplained decrement in tracking performance was observed.

Emotional stress elicits cardiovascular changes mediated through adrenergic alpha and beta receptors. Thus, there is a rise in both systolic and diastolic blood pressure, heart rate and cardiac output increases, and the total peripheral resistance falls. Acceleration stress ($+G_z$) also elicits a cardiovascular response, both directly, from the increased hydrostatic pressure gradient which results in a fall in blood pressure at head level and a decrease in venous return from dependent parts of the body; as well as indirectly, the fall in blood pressure triggering a compensatory reflex whereby heart rate is increased, peripheral resistance rises and blood pressure and cardiac output tend to return towards normal. This response is similar to that seen in emotional stress though, classically, the rapid reflex increase in heart rate is attributed to a reduction in vagal tone.

The terms alpha and beta adrenotropic (adrenergic) receptor were proposed by Ahlquist in 1948 on the basis of the differing potencies of a series of catecholamines in eliciting responses in various adrenergically controlled effector systems. Thus, adrenaline and noradrenaline were most potent in constricting arteries, an action blocked by ergot alkaloids, whereas isoprenaline had its greatest effect on the heart and actually relaxed arterial smooth muscle. It was not until 1958, however, that a drug which specifically blocked this type of action was discovered (dichloroisoprenaline). More recently, a considerable number of such beta blocking drugs has been introduced and one of these, oxprenolol (Trasicor, CIBA or 1-(-o-allyloxyphenoxy)-3-isopropylamino-2-propanol hydrochloride) has been used in an attempt to identify the relative roles of the vagus and of alpha and beta receptors in the cardiovascular response to acceleration stress.

Acceleration stress is complex in that it has an emotional impact as well as a direct physical one, as evidenced by an anticipatory tachycardia (Howard, personal communication). However, the extent to which the maintained increase in heart rate is of emotional origin has not been defined. Oxprenolol was, therefore, used in a double blind trial to investigate the part played by beta adrenergic receptors in the heart rate and blood pressure response to acceleration. Further differentiation between emotional and physical stress responses was attempted by comparing a group of practiced centrifuge subjects with a group of subjects who had not previously ridden on the centrifuge.

METHOD

Subjects

Twenty-four subjects were used in the study. Twelve had ridden regularly on the centrifuge, most over a period of years and all within the weeks preceding the trial. The other 12 had not ridden before, though one of them (J.T.) had experienced acceleration in a high performance aircraft. Physical details of the subjects are set out in Table 1. Each group, experienced and novice, was divided randomly into two groups of six, one group having their first trial exposure following beta blockade, whilst the other had their first trial exposure following a placebo injection. This was done in anticipation of a considerable order effect, since, following their first trial exposure, novice subjects would no longer be inexperienced.

Protocol

Subjects received two training sessions in order to achieve stable performance at a pursuit rotor tracking task (Ammons, 1947). They then attended for centrifuge runs on two mornings separated by an interval of from four to nine days. They had neither breakfast nor sweet or stimulating drink before arrival, and sessions started at either 0930 or 1100 hrs: where possible the same time was used on each occasion. On arrival at the laboratory the subject's current state of fitness and the amount of sleep obtained the previous night was assessed for comparison with his second run. He was then fitted with e.c.g. electrodes and a cannula was inserted into a vein in the left cubital fossa (right in left-handed subjects). The subject then walked into the centrifuge chamber and was strapped into a seat in the gondola. The electrodes were connected for the continuous recording of heart rate, and a microphone and cuff were

TABLE 1

Subject group	Subject	Age	Weight (kg)	Height (cm)
Experienced, drug first (D-P)	ED	40	83.5	191
	AG	33	85.7	184
	RC	28	73.0	185
	DC	42	73.0	173
	EP	33	76.2	183
	DG	37	76.2	183
average		35.5	77.93	183.1
Experienced, placebo first (P-D)	PH	45	73.5	178
	DR	35	84.4	182
	PF	30	80.3	193
	CB	52	78.9	175
	AN	36	79.4	178
	MH	25	58.1	179
average		37.2	75.74	180.9
Novice, drug first (D-P)	RT	22	75.3	173
	PW	24	65.3	161
	MB	22	65.3	179
	NW	25	78.0	187
	JT	53	83.9	175
	PS	19	64.9	173
average		27.5	72.11	174.6
Novice, placebo first (P-D)	JJ	31	71.2	178
	RB	22	72.6	173
	RG	23	70.8	183
	RE	20	61.7	168
	RR	39	95.7	196
	AA	21	70.3	183
average		26.0	73.70	180.0

Table 1. Physical details of the 24 subjects.

TABLE 2

Time	Procedure
Arrival	Subjective rating 1
	Electrodes applied
	Subjective rating 2
	Cannula inserted
0	Blood sample 1
5	Subject to centrifuge
	ECG leads connected
	BP cuff applied
10	Rest
20	Start HR & BP recording
24	Subjective rating 3
25-27	Blood sample 2, inject drug or placebo
38	Subjective rating 4
39	Start pursuit rotor test
53	Blood sample 3
54	Subjective rating 5
55	Run 1. $+2G_z$ for 60 secs
60	Subjective rating 6
61	Run 2. $+3G_z$ for 60 secs
64	Blood sample 4
66	Subjective rating 7
67	Run 3. 0.1G/sec to grey-out.
72	Blood sample 5
	Leave centrifuge
	Remove electrodes & cannula
	Complete questionnaire
Departure	Subjective rating 8

Table 2. Summary of experimental protocol.

applied to the upper arm opposite the cannula for indirect recording of blood pressure. The technique used allowed two or three determinations of systolic and diastolic pressure each minute.

The subject rested for 10 minutes and recording of heart rate and blood pressure was then carried out for 5 minutes before the oxprenolol or placebo injection (see Table 2). A further 5 minutes of monitoring followed and the pursuit rotor test started some 12 minutes after the injection. Five, two minute sessions with one minute rest periods led up to the first centrifuge run which started 30 minutes after the injection. Blood pressure was not monitored during use of the pursuit rotor since inflation of the cuff hampered arm movement. Upon completion of the rotor test the cuff was reconnected and the subject informed that he was shortly to experience a centrifuge run "at a low level of acceleration, lasting for one minute", whereupon the gondola door was closed. Some 60 sec later the subject was accelerated to $+2G_z$ with an onset rate of 1G/second and maintained at peak acceleration for one minute. The centrifuge was then stopped (at 1G/sec) and, after a five minute rest, the subject prepared for his second run. He was told that he was about to be exposed to "a rather greater acceleration lasting for the same time" and that there was "a slight chance of loss of vision". The use of a multiple light and button system to record loss of peripheral and central vision was explained to him. The gondola door was closed and, after a similar delay, he was accelerated to $+3G_z$, with onset rate, duration and offset as in the first run.

After a further five minute rest period he was told that a third and final run would be carried out, that this time the rate of onset would be much slower (0.1G/sec), but that the level of acceleration would continue to increase at this rate until he lost peripheral vision: that is, until he failed to respond to the outer white lights when they were illuminated. He was also told that, at this point, the centrifuge would be brought to a rapid standstill using the emergency stop system, and that this deceleration could give him an illusion of tumbling. The gondola door was then closed and the run carried out, again starting after a delay of some 60 sec. Recording was continued for a further five minutes after the run whereupon the cuff, leads, and cannula were removed, and the subject allowed to leave.

Blood samples for estimation of glucose, lactate, glycerol and non-esterified fatty acids were taken on five occasions, and subjective assessments of anxiety made by use of a 10 cm scale on eight occasions during each experiment as indicated in the summary protocol (Table 2). Detailed results of these findings are not included in the present paper.

EXPERIMENTAL TECHNIQUES

Oxprenolol Administration

Oxprenolol, 25 mg in 10 ml normal saline, was injected slowly through an indwelling venous cannula in a dose of 0.2 mg/kg body weight, taking one to two minutes to complete the injection. In placebo runs an equivalent volume of normal saline was injected in like manner, neither the subject nor experimenter being aware of the nature of the injection.

Heart Rate

Heart rates were obtained by counting over 15 sec periods from a recorded electrocardiogram (chest electrodes and a preamplifier in the centrifuge gondola) and also, for monitoring by the observer during runs, electronically from the R-R interval (i.e. see Fig.2). Rates were obtained for five minute periods preceding and following the oxprenolol or placebo injection, for 18 min before, during and following the tracking task and for six minutes before, during and following each of the three centrifuge runs.

Blood Pressure

An open based capsule was placed over the brachial artery at the junction of the middle and lower thirds of the upper arm, and held in place by the lower part of a snugly fitted sphygmomanometer cuff. The capsule was connected by thick walled plastic tubing to a microphone isolated from extraneous noise by plastic foam. This system was found to furnish clearly defined Korotkov sounds when cuff pressure lay between systolic and diastolic blood pressure (Fig.1). The cuff was inflated automatically to a value above systolic pressure and allowed to deflate over about 20 sec through a pneumatically controlled needle valve set to provide an approximately linear fall in cuff pressure (Fig.1). Reinflation was triggered when cuff pressure fell to a preset value close to atmospheric pressure. Confirmation that the technique provided a reliable measure of systolic pressure was obtained in all subjects by palpation at the wrist whilst observing the recorded sounds on closed circuit television.

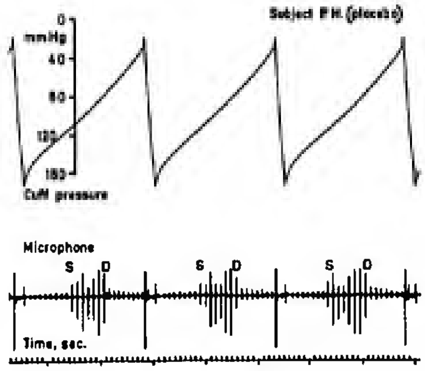

Fig. 1 Recording of sounds from brachial artery and of pressure in the overlying cuff. Systolic (S) and distolic (D) points are indicated.

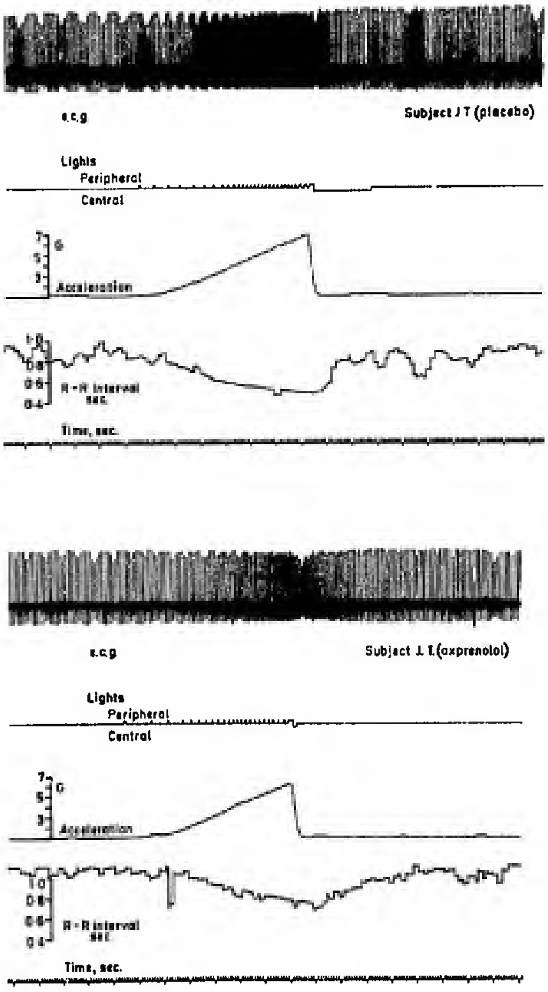

Fig. 2 Electrocardigram (ecg), switching of peripheral and central lights, acceleration, and R-R interval recorded during exposure to acceleration with a rate of increase of 0.1 G/sec.

Greyout Threshold

Subjects were presented with a pair of white lights illuminated in the periphery of their field of vision which they cancelled using a hand held push button. Failure to cancel indicated loss of peripheral vision whereupon a centrally sited light was illuminated and the centrifuge brought to rest. The subject's response to the central light indicated maintenance of central vision. Acceleration and switching of the light was recorded (Fig.2) and the level of acceleration at which the peripheral lights first failed to be cancelled was estimated and used as a measure of greyout threshold. Subjects were instructed to relax, but the novice subjects were not expected to take this instruction too seriously.

RESULTS

Heart rates recorded throughout the experiment are illustrated for two subjects in Figure 3. Figure 3a shows results from a novice subject whose first run was on placebo and, by contrast, Figure 3b shows results from an experimental subject who received oxprenolol in his first injection.

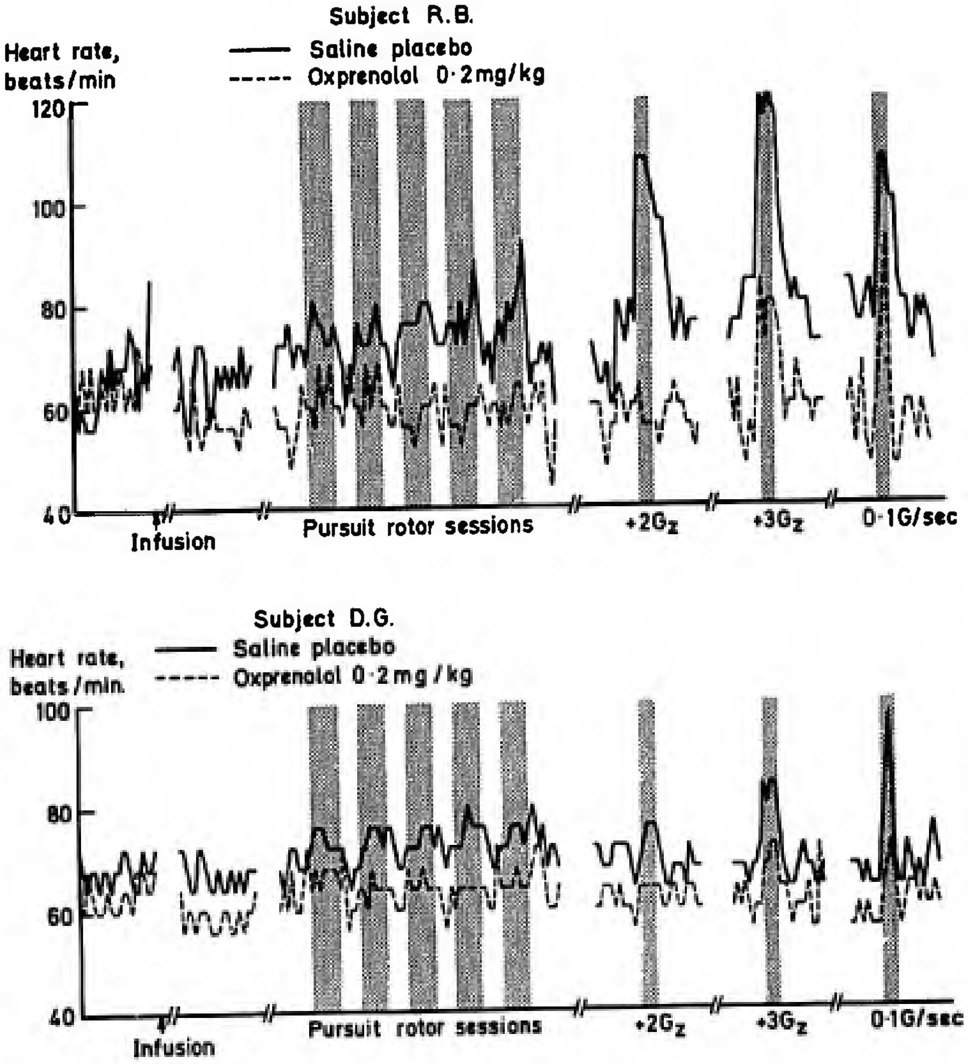

Fig. 3 Heart rates recorded from two subjects every 15 seconds during experiments with saline placebo (solid line) and with oxprenolol 0.2 mg/kg body weight (broken line). Upper record from a novice subject shows tachycardia in response to each stress situation and a steadily rising resting heart rate. The response is reduced by beta blockade and the resting heart rate remains steady. In an experienced subject (lower record), the heart rate response is less pronounced, though it is still reduced by beta blockade.

Resting Heart Rate

TABLE 3

Subject group	n	Average heart rate (beats/min), pre-injection First attendance	Second attendance	Difference, beats/min
Experienced, D-P	6	72.2 (63.4-89.0)	71.7 (58.2-80.8)	- 0.4
Experienced, P-D	6	66.7 (58.6-77.6)	65.5 (57.8-76.8)	- 1.2
All experienced	12	69.5	68.6	- 0.9
Novice, D-P	6	73.8 (59.4-106.4)	67.7 (55.6-94.8)	- 6.1
Novice, P-D	6	69.2 (59.4-79.4)	65.6 (57.2-84.0)	- 3.6
All novice	12	71.5	66.7	- 4.9
Total	24	70.5	67.6	- 2.9

Table 3. Average heart rates and ranges recorded in the four groups of subjects in the five minute period prior to the injection of oxprenolol (D) or placebo (P).

Table 3 gives average resting heart rates (beats per minute) and range, for each of the four groups of subjects on their first and second attendance. In each case the period referred to is the five minutes leading up to the injection of drug or placebo. Heart rates are higher on the first attendance in all four groups, but the difference is more pronounced in novice subjects.

The effect of oxprenolol, 0.2 mg/kg, is shown in Table 4, average heart rates being given for the four groups of subjects for five minute periods before and after the slow injection. Oxprenolol reduced the resting heart rate by an average of 5.2 beats/min, a reduction in rate of 7.5%. The reduction was comparable for all groups, but analysis of individual changes showed that it tended to be greater in subjects with initially faster heart rates. An infusion of saline caused a slight, but insignificant, increase in resting heart rate, the rate rising from an average of 68.8 beats/min to 69.9 beats/min.

TABLE 4

Subject group	n	Average heart rate and range (beats/min) 5 min pre-injection	 5 min post-injection	Decrease Beats/min	 Per Cent
Experienced, D-P	6	72.2 (63.4-89.0)	66.1 (58.8-80.6)	6.1	8.4
Experienced, P-D	6	65.5 (57.8-76.8)	60.4 (52.0-72.6)	5.1	7.9
All experienced	12	68.9	63.3	5.6	8.1
Novice, D-P	6	73.8 (59.4-106.4)	68.5 (56.2-90.6)	5.3	7.2
Novice, P-D	6	65.6 (57.2-84.0)	61.3 (57.0-68.8)	4.3	6.6
All novice	12	69.7	64.9	4.8	6.9
Total	24	69.3	64.1	5.2	7.5

Table 4. Average heart rates and ranges recorded in the four groups of subjects in the five minute periods before and after an injection of oxprenolol, 0.2 mg/kg body weight.

Resting Blood Pressure

Ten estimates of systolic and diastolic blood pressures were made during the five minutes pre-injection, and a further ten immediately following the injection. These estimates were averaged to give a representative value for each subject and the group averages when the injection was of oxprenolol are given in Table 5. There is a reduction in systolic pressure of 2.7 mm Hg which is probably significant ($P < 0.05$) and a smaller (1.1 mm Hg) decrease in diastolic pressure which was not statistically significant. An infusion of saline had no effect on resting blood pressure; nor were the resting pressures significantly different on the two attendances.

TABLE 5

Subject group	n	Average blood pressure pre-injection Systolic	 Diastolic	Average blood pressure post-injection Systolic	 Diastolic
Experienced, D-P	6	115 (107-131)	79 (70-84)	113 (105-129)	78 (73-85)
Experienced, P-D	6	108 (95-124)	77 (68-88)	107 (100-124)	75 (68-83)
Novice, D-P	6	118 (102-144)	79 (65-96)	116 (104-149)	80 (65-97)
Novice, P-D	6	112 (96-127)	73 (61-83)	108 (96-120)	71 (63-83)
Total	24	113.4	77.0	110.7	75.9

Table 5. Systolic and diastolic blood pressure in the four groups of subjects in the five minutes before and after an injection of oxprenolol, 0.2 mg/kg body weight.

Base Line Heart Rate

The increase in heart rate seen during rest periods throughout the experiment in most subjects during their placebo runs (i.e. Fig.3a) was examined by taking the heart rates for the fifth minute post-injection and for the penultimate minutes preceding the rotor test and the three centrifuge runs. These values, for drug and placebo, together with the pre-injection heart rate (penultimate minute preceding injection) are plotted in Figure 4. In the placebo runs (solid lines) there was a continuous increase in heart rate throughout the experiment, more marked in the novices than in the experienced subjects. Statistical analysis showed that the final heart rate was greater than earlier values ($P < 0.05$) and that the pre-acceleration heart rates were significantly greater than the first three values ($P < 0.01$). This increase was abolished by an injection of oxprenolol (dashed line), the lowest heart rate then being seen preceding the final centrifuge run. In this graph order effect was cancelled out by combining the two novice and the two experienced subject groups. The initial fall in rate following oxprenolol was highly significant ($P < 0.001$), but thereafter the rate remained effectively constant. The difference between oxprenolol and placebo heart rates was also highly significant ($P < 0.001$).

Pursuit Rotor - Heart Rate Changes

Figure 5 illustrates the average heart rates for each 15 sec period in the two minutes leading up to the first two minute session of tracking. Rates given for the tracking and for the first minute of recovery are average values for all five sessions, while the last minute of recovery refers to the second minute following the fifth session (there was only one minute between each session). An order effect (drug-placebo, placebo-drug) was not seen and the results have been combined. On placebo, the heart rate rose over the second minute of tracking by 6.6 and 7.0 beats/min for the experienced and novice groups, whereas on oxprenolol the increase was considerably less, 3.5 and 4.7 beats/min respectively. It is noticeable that rates increase more, and to higher values, in novice subjects, though qualitatively the two groups behave in the same way. Thus, heart rates increase over the first minute and tend to level off towards the end of the tracking session, then fall rapidly towards resting values during the first half minute of the recovery period.

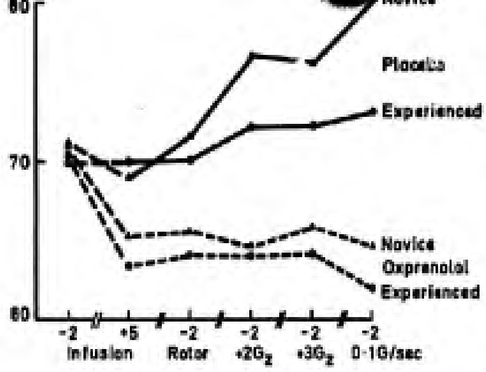

Fig. 4 Resting heart rates in four groups of subjects throughout the experiments. The steady rise, more marked in novice subjects on placebo, is abolished by oxprenolol.

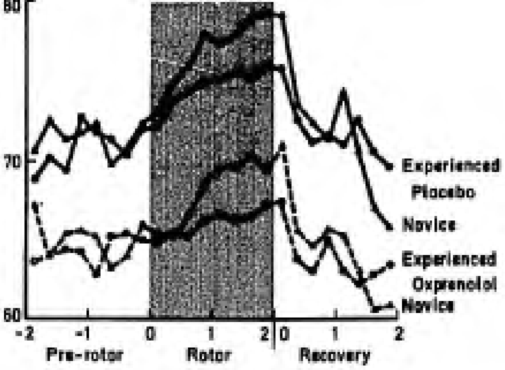

Fig. 5 Heart rates obtained from four groups of subjects during pursuit rotor tracking task. Rates during tracking and in the following minute are averaged from the five sessions.

While the response to tracking seen in Figure 5 was typical (by definition, since these are average results), individuals differed considerably in the extent of the changes and one subject even exhibited relative bradycardia during tracking (Fig.6). This phenomenon was more pronounced on placebo than following oxprenolol.

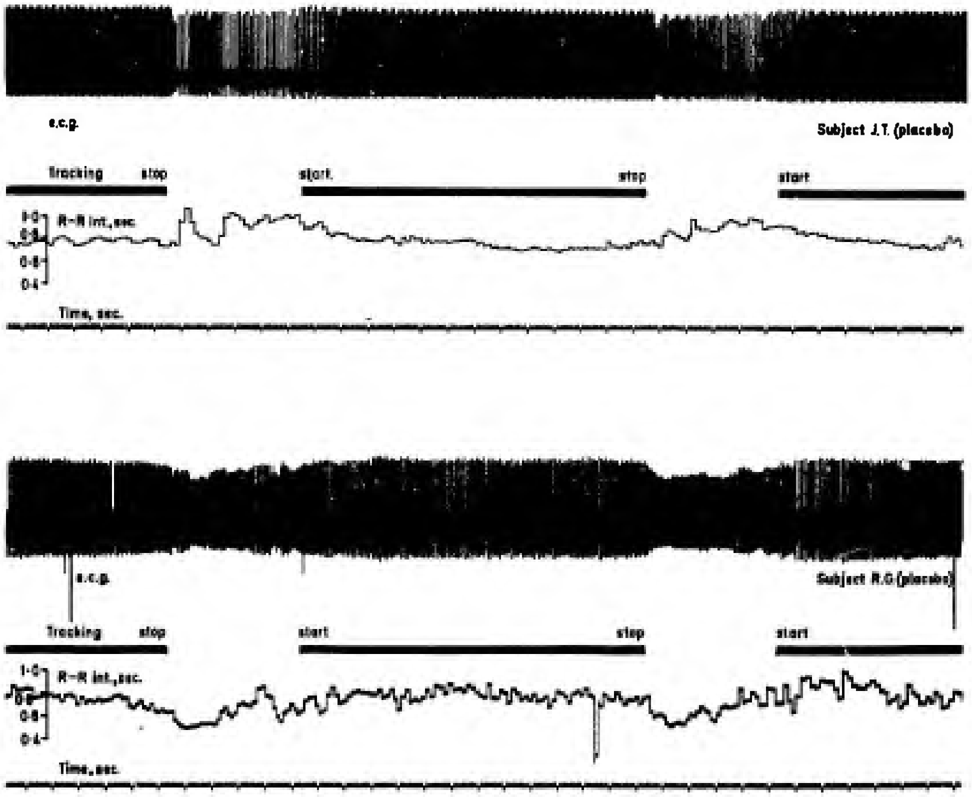

Fig. 6 Electrocardiogram (ecg) and R-R interval recorded from two subjects during three tracking sessions and the intervening two rest periods. The upper record is an example of the typical response with tachycardia during tracking (cf figure 5), whilst the lower record is from a subject showing relative tachycardia during rest periods.

Figure 7 illustrates th[illegible]cent time of each two minute tracking session during which the subjects stayed on the rotor target. Performance generally improved during the early sessions and tended to level off by the fourth session. However, oxprenolol resulted in an overall decrease of time on target and, in the experienced subjects, in a terminal fall off in performance. The effect of oxprenolol is significant at the $P < 0.05$ level.

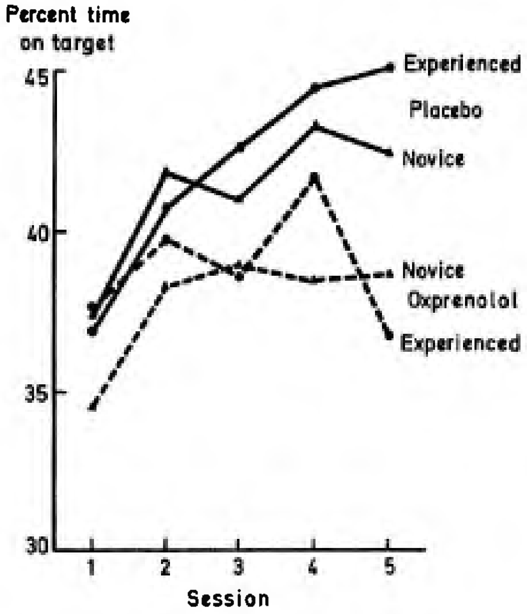

Fig. 7 Effect of oxprenolol on tracking performance in experienced and novice subjects. Improvement continues over the five sessions in placebo runs, but tends to level off, or even to degenerate, following beta blockade.

$+2G_z$ Acceleration, Heart Rate Changes

In Figure 8, the four subject groups have been plotted separately to demonstrate the marked order effect. On placebo (Fig.8a), all four groups showed an increase in heart rate during the 15 sec preceding the onset of acceleration, and an even greater increase during the next 15 sec. Heart rates then fell towards control values, but remained elevated to the end of the 60 sec acceleration plateau. Recovery was usually complete within 30 sec of the centrifuge coming to rest. The increase in heart rate was more marked in the novice subjects, especially so in the group experiencing its first ever centrifuge run (novice, P-D), where the increase, averaged over the entire acceleration plateau, was 21.4 beats/minute or 28.2%.

On oxprenolol (Fig.8b), there was a small increase in heart rate during the first 15 sec of the run in three of the groups, the largest increase (3.8 beats/min; 5.8%) being seen in the group experiencing its first ever run (novice, D-P). During the remaining 45 secs of the acceleration exposure heart rates did not differ significantly from control values. In Figure 9 the order effect has been cancelled out by combining the two novice and two experienced subject groups, and the effect of oxprenolol can be seen more clearly.

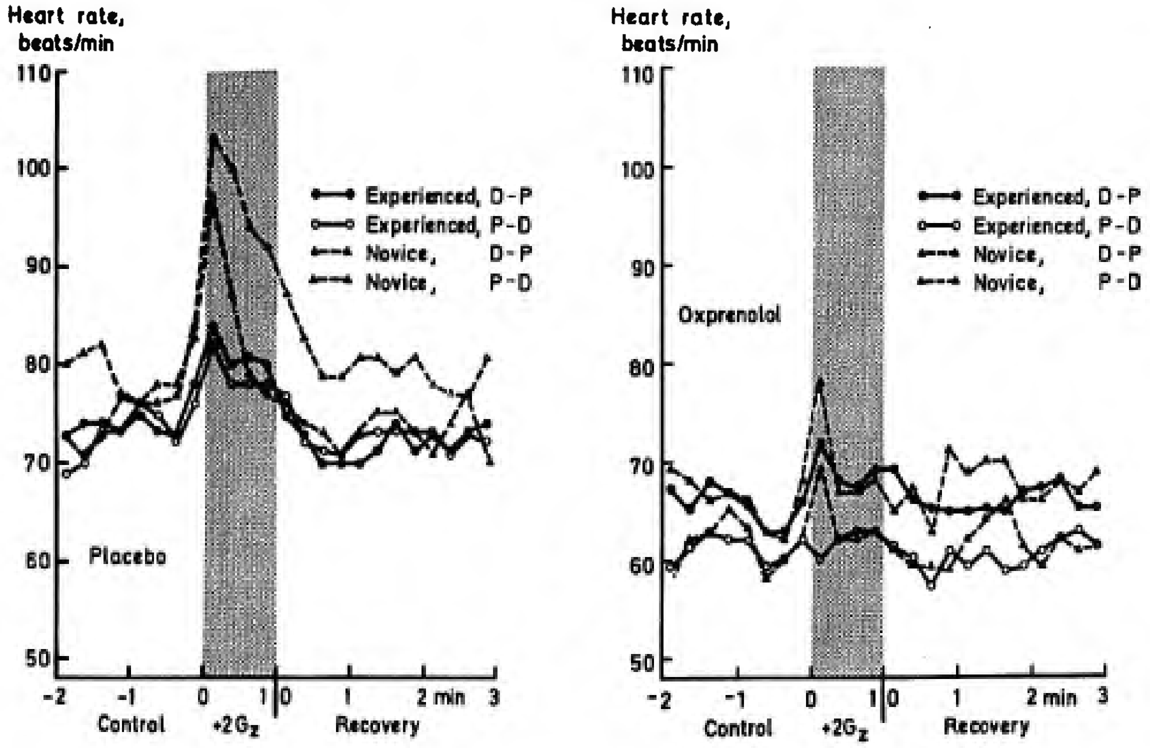

Fig. 8 Heart rates recorded every 15 seconds during exposure to $+2G_z$ acceleration in the four subject groups following placebo (left) and oxprenolol (right). In each graph, the group showing the greatest tachycardia on initial exposure to acceleration is the novice group experiencing its first centrifuge run.

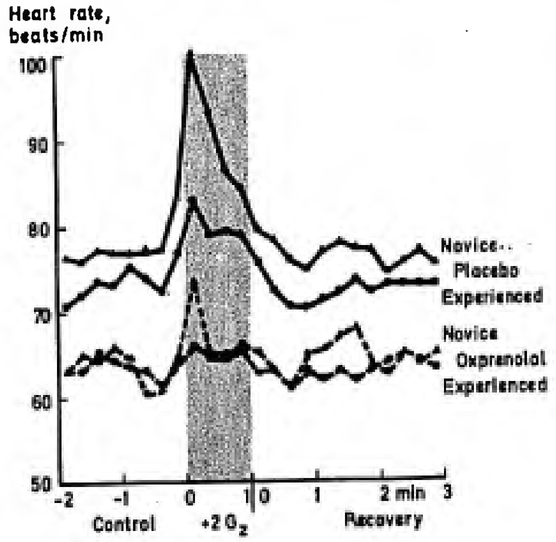

Fig. 9 As for figure 8, but with order effect removed by combining placebo-drug and drug-placebo groups. Note the virtual lack of response in experienced subjects following beta blockade.

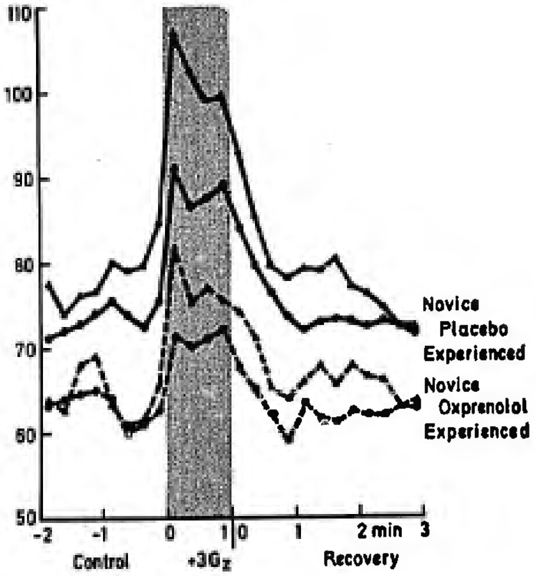

Fig. 10 Heart rate responses to $+3G_z$ acceleration plotted as in figure 9. At the higher level of acceleration, experienced subjects exhibit a tachycardia which is reduced, but not abolished, by beta blockade.

$+3G_z$ Acceleration, Heart Rate Changes

The order effect was less marked in the second, $+3G_z$ centrifuge run, and in Figure 10 the groups have been combined to show the effect of oxprenolol. As at $+2G_z$, there is a pronounced tachycardia during the first 15 sec of the run, and this subsides somewhat for the last 45 sec. Recovery takes rather longer than following $+2G_z$, but is complete after 60 sec in all but the novice placebo group. The tachycardia is more pronounced in placebo runs, the increase in heart rate over the last 45 sec of the run being 14.4 beats/min for the experienced subjects (19.6%) and 21.8 beats/min (27.8%) for the novices. On oxprenolol the increases were 7.9 beats/min (12.5%) and 11.5 beats/min (17.9%) respectively.

$+3G_z$ Acceleration - Blood Pressure

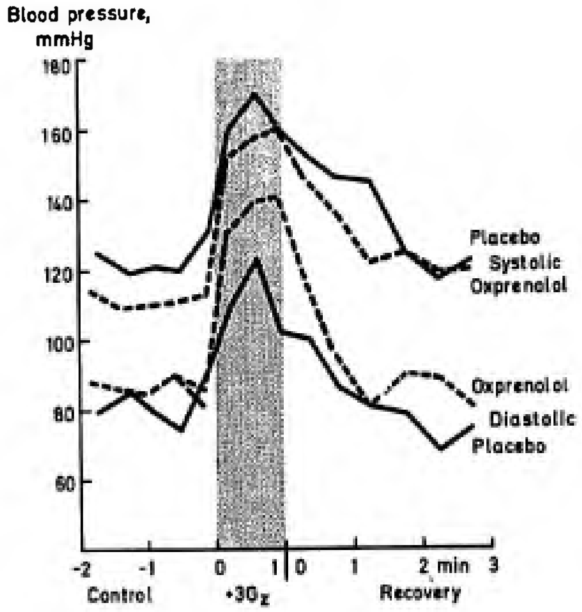

Fig. 11 Systolic and diastolic blood pressure recorded in one subject during exposure to $+3G_z$ acceleration. Beta blockade narrows the pulse pressure, especially during acceleration, but mean pressure is virtually unchanged.

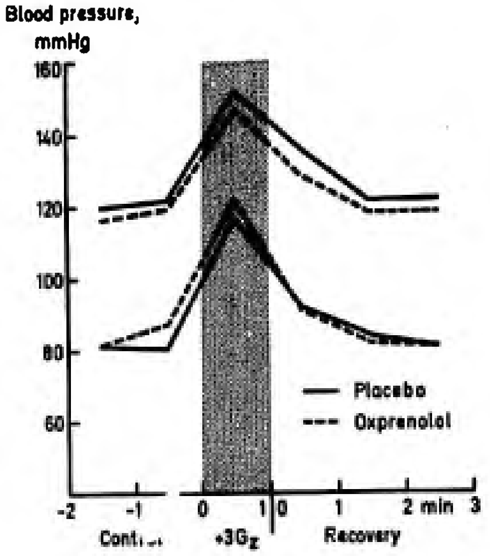

Fig. 12 Blood pressure response to $+3G_z$ acceleration averaged from 19 subjects. The reduction in pulse pressure seen during acceleration following beta blockade is statistically significant (P = <0.01).

Figure 11 illustrates the change in blood pressure seen in one subject during exposure to $+3G_z$. There is an increase in both systolic and diastolic pressures of some 40 mm Hg at peak acceleration, recovery to normal values taking some two minutes from return to 1G. Oxprenolol has little effect on mean pressure, nor on the time course of the changes, but pulse pressure is narrowed at 1G and narrowed still further at $+3G_z$. Figure 12 illustrates average results obtained from the 19 subjects on whom satisfactory pressure recordings were obtained during both $+3G_z$ acceleration exposures. A similar trend is seen, the increase in systolic pressure being highly significant ($P < 0.001$) and that in diastolic pressure significant ($P < 0.01$). Neither value had returned to normal in the minute following the acceleration exposure ($P < 0.001$ or < 0.01 respectively). The reduction in systolic pressure seen following oxprenolol was not statistically significant, but the increase in diastolic pressure seen at $+3G_z$ was ($P < 0.01$). A further statistical analysis of pulse pressures demonstrated a significant reduction at $+3G_z$ on placebo ($P < 0.01$) and a further reduction at $+3G_z$ following beta blockade ($P < 0.01$). On oxprenolol, the reduction in pulse pressure at $+3G_z$ was highly significant ($P < 0.001$).

0.1G/sec Ramp Acceleration - Heart Rate

TABLE 6

Subject group	n	Average heart rate and range (beats/min) Placebo	Oxprenolol	Decrease Beats/min	Per Cent
Experienced, D-P	6	104.2 (87.6-129.6)	78.0 (66.0-93.6)	26.2	25.1
Experienced, P-D	6	95.7 (79.2-123.6)	72.6 (68.4-78.0)	23.1	24.1
All experienced	12	100.0	75.3	24.7	24.7
Novice, D-P	6	122.8 (87.6-192.0)	90.8 (66.0-126.0)	32.0	26.1
Novice, P-D	6	119.0 (93.6-146.4)	89.6 (72.0-116.4)	29.4	24.7
All novice	12	120.9	90.2	30.7	25.4
Total	24	110.4	82.8	27.7	25.0

Table 6. Average heart rates and ranges observed in the four groups of subjects in the last five seconds of the 0.1 G/sec ramp acceleration exposure.

Due to the variable duration of this run which depended upon the subject's individual tolerance, and due to the lack of a steady state stress, heart rates were computed from the final five seconds of the run during which time all subjects lost peripheral vision. The results are given in Table 6. The highest rates were again seen in the two novice groups, one subject exceeding 190 beats/min at a final acceleration level of $+5.6G_z$. Oxprenolol decreased these peak rates by from 23 to 32 beats/min, an average reduction of 25%, though the average acceleration stress was unaltered (see below).

0.1G/sec Ramp Acceleration - Greyout Threshold

Table 7 gives the greyout thresholds for the four groups of subjects. Oxprenolol had no significant effect on threshold, but novices showed a higher threshold than experienced subjects (difference of 0.8G, $P < 0.001$). Also indicated on this table are the occasions where the preceding $+3G_z$ run had caused greyout. This occurred on 10 occasions in experienced subjects and on only three occasions in novice subjects. There was no significant difference between placebo and oxprenolol in this respect, though the tendency was for greyout to occur more frequently during placebo runs (eight out of 13 instances).

TABLE 7

Subject		Greyout tolerance (G)		
		Placebo	Oxprenolol	Difference
Experienced, (D-P)	ED	4.2*	4.1	-0.1
	AG	5.5	4.6	-0.9
	RC	3.4*	3.8*	+0.4
	DC	5.0	4.7	-0.3
	EP	4.2*	4.4	+0.2
	DG	4.0*	4.5	+0.5
Experienced, (P-D)	PH	5.2	4.1*	-1.1
	DR	3.7*	4.2*	+0.5
	PF	4.6	4.8	+0.2
	GB	3.6*	3.2*	-0.4
	AN	4.1	3.9	-0.2
	MH	4.7	4.9	+0.2
Average		4.35	4.27	-0.08
Novice, (D-P)	RT	4.4*	4.0*	-0.4
	PW	3.2*	4.0	+0.8
	MB	5.6	6.2	+0.6
	NW	4.5	4.8	+0.3
	JT	6.8	6.0	-0.8
	PS	6.7	5.4	-1.3
Novice, (P-D)	JJ	5.9	5.1	-0.8
	RB	4.6	5.2	+0.6
	RG	4.5	5.4	+0.9
	RE	5.5	5.4	-0.1
	RR	5.4	5.2	-0.2
	AA	6.5	4.6	-1.9
Average		5.30	5.11	-0.19

Table 7. Greyout tolerances in the four groups of subjects following placebo and oxprenolol. Asterisks indicate where the preceding $+3G_z$ run was accompanied by greyout.

No attempt was made to test the completeness of the beta adrenergic blockade obtained in our subjects, but Taylor (personal communication) has shown that the degree of block would have been adequate to abolish the heart rate response to an infusion of isoprenaline at a dose rate of 10 µg/min, and that this level of block would have persisted well beyond the end of the experimental period. This supposition is borne out by the constancy of the resting heart rates seen following oxprenolol, these actually being at their lowest prior to the last centrifuge run, or some 40 min following the onset of the blockade (Fig.4). However, block produced by oxprenolol, in common with other agents of this type, is competitive, and could be reversed if the local concentration of noradrenaline or other adrenergic stimulating substance were to rise high enough. There is some evidence that this may be happening in these experiments for, as illustrated in Figure 8b, initial exposure to $+2G_z$ acceleration induced a brief tachycardia in three of the four subject groups. The fact that the tachycardia was most pronounced in the novice group receiving its first centrifuge experience (novice, D-P), less marked in the novice P-D group having its second experience, of doubtful significance in the experienced D-P group, and absent in the experienced P-D group, despite identical physical stresses, suggests that the response was of emotional origin. That it was not just a feature of subject group differences is confirmed by the observation that, following placebo (Fig. 8a), the maximum tachycardia was seen in the novice P-D group.

A problem in interpreting the statistical results of the present trial was the presence of significant subject differences and order effects. Examination of Table 1 shows that the groups were reasonably matched in all but age. Age differences were unavoidable since the inexperienced subjects tended to be recent arrivals at the laboratory who were naturally younger than the experienced subjects. However, plots of some of the variables, control heart rate, post-infusion heart rate and acceleration tolerance, against age, failed to show up any correlation which would have biased the results.

Of more concern is the order effect. Thus, with the novice, P-D group, exposure to $+2G_z$ following a placebo injection was the group's first ever centrifuge experience, whilst with the novice D-P group, the corresponding run was the group's fourth centrifuge experience. However, on the basis that subject differences, though statistically significant, are unimportant in terms of response to oxprenolol, the results obtained from the two groups can be combined to eliminate this effect. This approach was carried out in constructing most of the figures, though details of each group are retained in the tables.

Following a 10 min rest period, heart rates were higher on the subject's first experimental attendance than on his second attendance, an indication of the greater emotional stress which the first attendance in a novel situation engendered. As might have been expected, this difference was much more pronounced in the novice subjects where it averaged 4.9 beats/min (Table 3). Beta blockade reduced the resting rate in all but one subject, the average reduction being 5.2 beats/min or 7.5%. The exception, subject PS, was the youngest subject and, because he was also the lightest, received the lowest total dose of oxprenolol (13.0 mg). He maintained his apparent indifference to beta blockade throughout the experiment, a finding which cannot be satisfactorily explained. His results have not, however, been excluded in calculating average values.

The reduction in heart rate produced by oxprenolol was rapid, heart rates recorded in the first minute following the slow injection not differing significantly from those recorded over the subsequent four minutes. The degree of reduction was maintained until termination of the recording, and actually appeared to increase, a natural consequence of the fact that, on placebo, resting heart rates rose steadily (Fig.4). Since oxprenolol can have no effect on vagus induced heart rate changes, it follows that a degree of adrenergic 'tone' is present at rest, and that the increase in resting heart rate seen as the experiment proceeded was also adrenergically induced. It is not possible to differentiate between neuronal or humoral mechanisms for this increase, however, since the effector substances are similarly blocked by oxprenolol. It is tempting to suggest that the steady increase in resting rate, abolished by oxprenolol and most marked in novice subjects during their first experience of the centrifuge (i.e. Fig. 3a), was caused by activation of the adrenal medulla with a consequent increase in plasma catecholamine levels. Unfortunately, no direct estimation of plasma adrenaline or noradrenaline was possible. However, non-esterified fatty acid levels in the plasma were found to increase during placebo runs ($P < 0.001$) and the increase was most marked in novice subjects during their first centrifuge experience: this response was abolished by oxprenolol ($P < 0.01$) (Table 8). Since an action of adrenaline and noradrenaline is the mobilisation of fat stores in adipose tissue to give non-esterified fatty acids (Lundholm et al, 1968), and since this action is inhibited by beta blockade (Hunninghake et al, 1967), the observation supports the supposition that catecholamines are also responsible for the increase in base line heart rate.

TABLE 8

Subject group	n	Non-esterified fatty acid (mEq/L) Placebo Samples 1-3	 Samples 4&5	 Oxprenolol Samples 1-3	 Samples 4&5	Difference (%) Placebo	 Oxprenolol
Experienced, (D-P)	6	.25 (.03-.56)	.32 (.07-.64)	.21 (.14-.28)	.23 (.14-.34)	+25	+ 8
Experienced, (P-D)	6	.20 (.09-.38)	.39 (.18-.54)	.24 (.07-.36)	.19 (.10-.25)	+91	-21
All experienced	12	.23	.35	.22	.21	+52	- 7
Novice, (D-P)	6	.27 (.16-.60)	.48 (.19-.75)	.27 (.16-.40)	.30 (.20-.52)	+77	+ 9
Novice, (P-D)	6	.34 (.17-.81)	.60 (.14-1.66)	.18 (.03-.27)	.24 (.05-.42)	+79	+33
All novice	12	.30	.54	.23	.27	+78	+19
Total	24	.27	.45	.22	.24	+69	+ 6

Table 8. Effect of beta blockade on non-esterified fatty acid levels (and ranges) in the four groups of subjects. Samples 1-3 were obtained before the first centrifuge run, samples 4&5 afterwards (see Table 2).

Similar arguments may be applied to the virtually complete block of the heart rate response to $+2G_z$ acceleration (Figs. 8 and 9). Here, however, the tachycardia is so transient that it is presumably mediated via the cardioacceleratory fibres of the sympathetic system. The apparent breakthrough of sympathetic drive seen in novice subjects during the first 15 sec of acceleration exposure has already been commented upon.

Whilst the increase in base line heart rate and the tachycardia produced by exposure to $+2G_z$ acceleration were abolished by beta receptor blockade, this is not the case for the tachycardia seen at $+3G_z$ (Fig.10), or for that recorded during the final five seconds of the 0.1 G/sec ramp acceleration run (Table 6). However, in both these situations the degree of tachycardia is considerably reduced, and it must be concluded that several mechanisms are acting. First, a fall in blood pressure at the level of the carotid bifurcation stimulates the baroreceptor reflex which accelerates the heart via a reduction in vagal tone (unaffected by oxprenolol). Secondly, part of this reflex is probably mediated via sympathetic fibres and this component will be blocked by oxprenolol. However, it has been shown that this response is considerably slower than that mediated through vagal efferents (Wang & Borison, 1947). Thirdly, emotional factors operating through the brain stem and sympathetic system could increase the heart rate. Finally, humoral factors could be involved with sympathetic stimulation of the adrenal medulla causing a release of catecholamines, though the short duration of the response makes this mechanism unlikely. It is concluded that the tachycardia seen at $+3G_z$ following beta blockade must be a baroreceptor response mediated via the vagus, all other potential mechanisms being blocked, whilst the extra increase in heart rate seen in the absence of beta blockade is a combination of a slower sympathetically innervated component of the baroreceptor reflex and an emotionally induced tachycardia. The fact that the reduction in heart rate following beta blockade is greater in novice subjects, especially during their first experimental attendance, suggests that the emotional component is quite large.

Heart rate showed a rather different response during tracking, in that the onset of the tachycardia was slow, only levelling off towards the end of the two minute sessions. As with the other stresses, however, novice subjects showed a more pronounced response (Fig.5). A considerable physical effort was involved in the tracking, as subjects had to lean forward to reach the rotor (a similar posture was used for training sessions), and this posture had to be held rigidly in order to fix the operating shoulder. Tracking movements were considerable, the rotor having an effective diameter of 16.5 cm, and no elbow fixation was possible. It follows that the tachycardia seen could be a response to physical exertion, a supposition supported by its slow onset and by the observation that, whilst heart rate was decreased by oxprenolol, the degree of reduction was not noticeably greater during tracking than during the rest periods. The response was, however, quite variable, as evidenced by the subject who showed a relative bradycardia during tracking (Fig.6). It is noted that exercise tachycardia is only reduced by a small extent by beta adrenergic blockade (Eliasch et al, 1967).

A surprising feature of the tracking task results was the reduction in percent time on target seen with oxprenolol. This feature was present in all four subject groups and was probably statistically significant. Subjects were quite unaware that they had been given the drug, and subjective assessment ratings showed no difference between placebo and oxprenolol runs. Heart rates returned rapidly to low resting levels following the last tracking session (Fig.6), an indication that subjects were under no great stress at this stage of the experiment despite the imminence of a centrifuge run. It is not possible on the basis of a single task to identify the mechanism responsible, even to the extent of suggesting whether it is acting centrally or peripherally. Further tests are indicated, under similar double blind conditions, making use of tasks of varying mental and motor complexity.

Resting blood pressure was little affected by the injection of oxprenolol, a small (2.7 mm Hg) reduction in systolic pressure being the only significant finding. While the even smaller rise in diastolic pressure was not statistically significant, the ensuing narrowing of pulse pressure (seen clearly in subject MH, Fig.11) suggests that the changes are probably secondary to a reduction in cardiac output following a decrease in heart rate. Direct measurement of cardiac output has demonstrated a reduction in resting subjects following beta blockade (Eliasch et al, 1967). Beta adrenergic stimulation of arterial smooth muscle causes relaxation, and block of these receptors would allow the vessels to constrict under the unopposed action of alpha receptor stimulation. In the absence of a fall in cardiac output this process would lead to an increase in systolic as well as diastolic pressure.

Acceleration caused an increase in blood pressure (Figs. 11 and 12), the measured pressures being referred to the upper margin of the sphygmomanometer cuff approximating, in seated subjects, to the level of the left ventricle. Pulse pressure was reduced, an indication of a fall in stroke volume and reflex increase in total peripheral resistance. Beta blockade led to a further decrease in pulse pressure, but mean arterial pressure was unaffected. The decrease in pulse pressure indicates a further reduction in cardiac output during acceleration (as expected from the lowered heart rate), again compensated for by an increase in peripheral resistance. These results warrant more direct measurement of the cardiovascular response to acceleration in the presence of beta blockade.

The only significant difference noted in greyout tolerances was the greater tolerance of novice subjects. This difference could not be related to age and must be attributed to the difficulty that subjects have in relaxing during their first few centrifuge runs. Whilst not statistically significant, threshold fell very slightly following oxprenolol. Examination of Table 7 shows that this fall is largely contributed by the novice, P-D group and probably merely reflects the better degree of relaxation achieved by these subjects on their second threshold run. The constancy of threshold, despite the reduced heart rate and presumed reduction in cardiac output produced by beta blockade, is surprising, but supports the observation that mean blood pressure is also unaffected, and confirms the adequacy of the raised peripheral resistance. Again, it is not possible to differentiate between a direct action of oxprenolol on the peripheral arteries, and a reflex vasoconstriction secondary to a fall in blood pressure at the carotid bifurcation.

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ACKNOWLEDGEMENTS

The authors wish to thank Ciba Laboratories, Horsham, Sussex, for the supply of Trasicor and provision of four novice subjects; Mr M R Farncombe for recording assistance; Mrs S E Kemp for record analysis; and Miss H Ferres for the statistical analysis. The authors also wish to thank the Director-General of Medical Services, Royal Air Force, for permission to submit this paper for publication.

DISCUSSION

KLEIN Dr. Glaister, I am sure you are aware of a paper which came out many years ago by Dr. Polis from the United States. This showed a high adrenalin output was correlated to, if I remember correctly, a poor G tolerance on the centrifuge, while higher nor-adrenalin output was correlated to better tolerance. Do you feel your results support those of Polis or are they in opposition to it?

GLAISTER In answer to your question concerning differential cathecholamine secretion and G tolerance, we have little evidence to offer, since we did not measure blood levels directly, but only looked at secondary effects - changes in glycerol, NEFA, etc. Our evidence suggests that the greater production of catecholamines in our novice subjects, as deduced from their more pronounced heart rate and biochemical changes and the block of these changes by oxprenolol, was associated with a higher G-threshold. This does not mean that catecholamines were responsible for the raised threshold - indeed, had this been the mechanism the G-threshold should have fallen following beta-blockade, which it did not.

ROSCOE Do you consider that the use of a beta adrenergic block such as oxpranolol has any value in the flight situations? For example, I suspect that the emotional content of the heart rate increase experienced during the landing phase in the experienced pilot is quite small. A beta block would presumably eliminate this factor.

It would have been interesting to have determined the effects of an atropine-like drug; though how you would prevent the subject from being aware of such a drug, I don't know.

GLAISTER It would be interesting to investigate the effect of atropine under these conditions, but I agree that it would be most difficult, if not impossible, to use this drug in a "double blind" controlled manner. The heart rate is increased in many conditions of emotional stress, and analysis of the ECG in, for example, car drivers or public speakers, showed changes such as ST depression or T-wave inversion, which are suggestive of myocardial ischaemia. The employment of beta-blockers not only slows the rate, but restores the ECG to a normal pattern (Paper presented by D. P. Taggert at a CIBA Symposium on "New Prospects in Beta-Blockade," held at Scanticon, Denmark, on May 21-22, 1972). There is a strong argument in favor of the use of a drug like oxpranolol during emotional stress - especially so since it is very possible that the "fright or flight" response is outmoded in the context of modern aircraft where we rely on machinery rather than muscles. The performance decrement which we demonstrated, while not yet confirmed by other studies, leads one to be rather cautious about prescribing a drug with a possible central action to pilots - certainly until appropriate trials in aircraft simulators have been made. However, one such simulator study, that reported by Eliasch, et al, and referenced to in our paper, did not show any increase in the number of errors made following beta-blockade with propranolol.

ESTIMATES OF PHYSIOLOGIC RESERVE AFTER ACCELERATION EXPOSURE IN MAN

by

Frank R. Lecocq, Colonel
Richard L. Lipman, Captain
Sidney D. Leverett, Ph.D.
USAF School of Aerospace Medicine
Brooks Air Force Base, Texas 78235

SUMMARY

A metabolic stressor was employed to provoke gluco-regulatory hormone response immediately after exposure of subjects to acceleration stress. 2-deoxy-D-glucose, a glucose analogue which produces severe intracellular hypoglycemia, was infused in eight normal male volunteers during a control period, immediately after an initial experience with acceleration and after their fourth exposure to acceleration. Blood glucose, free fatty acids, insulin, growth hormone and cortisol and urinary epinephrine and norepinephrine were measured before and after each infusion of 2-deoxy-D-glucose. Although acceleration stress was modest, readily discernible changes in gluco-regulatory response to the metabolic stressor were detected after exposure to acceleration.

SYMBOLOGY

mg/100cc - milligrams per 100 cubic centimeters

μ Eq/L - micro equivalents per liter

γ/100cc - gamma per 100 cubic centimeters

γ/Hr. - gamma per hour

ng/ml - nannagrams per milliliter

2-DG - 2-deoxy-D-glucose

$+G_z$ - acceleration with a head-to-foot vector

FFA - free fatty acids

S.E.M. - standard error of the mean

INTRODUCTION

Evaluation of stress response in humans does not generally include consideration of the physiologic reserve which remains and is available for subsequent stress exposures. In regard to flight stress, however, quantitative information concerning physiologic reserve has significant and practical value. It would provide a dynamic technique for evaluating flight-crew candidates and would be useful in evaluation of stress protective measures, as well as in clinical evaluation of stress adaptation. The current study is an introduction to this concept of stress physiology and has been designed to evaluate the influence of a biodynamic stress ($+G_z$ acceleration) on one aspect of physiologic reserve - gluco-regulatory hormone reserve.

Few published data are available regarding metabolic and endocrine responses to acceleration forces. Meyer (1) reported elevation in blood glucose concentrations in pilots during take-off and landings in the NF-100F aircraft. He attributed this elevation to epinephrine release secondary to acceleration stress. This assumption was confirmed by Goodall (2), who found increased urinary catecholamines during and immediately following acceleration exposure. Other hormonal studies during G exposure include measurements of parotid fluid 17-hydroxycorticosteroids (3) and blood antidiuretic hormone (4). Common to all of these studies, however, has been reliance on static hormone levels without the use of provocative tests capable of detecting alterations in the hormonal reserve.

The present study evaluates pituitary and adrenal hormone reserve in man immediately after acceleration stress. The glucose analogue, 2-deoxy-D-glucose (2-DG), was used as the provocative agent. The 2-DG administration results in a state of profound intracellular glucopenia with attendant, reproducible elevations in plasma glucose, free fatty acid, growth hormone, cortisol, and catecholamines, as shown in Figure 1 (5, 6). The subjects were tested after their initial experience to centrifugation (acute acceleration) and after their fourth acceleration exposure (chronic acceleration).

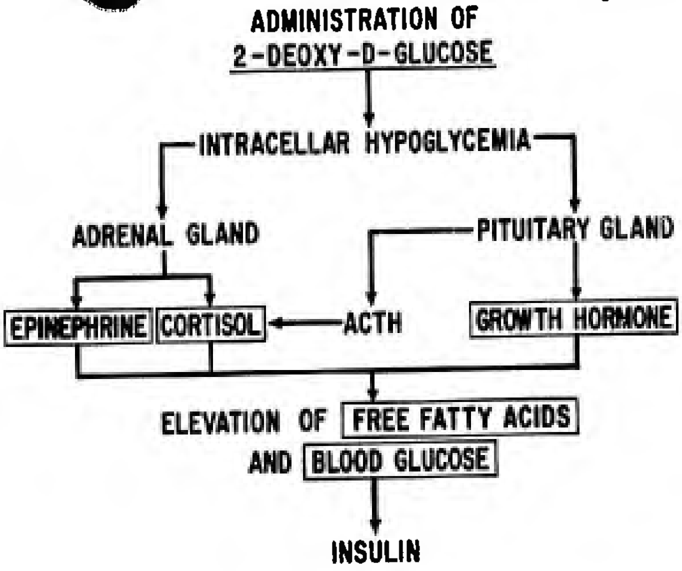

Fig. 1. THE METABOLIC CONSEQUENCES OF ADMINISTRATION OF 2DG. ☐ REFERS TO SUBSTANCES MEASURED.

METHODS AND MATERIALS

Eight normal, male volunteer basic airmen, 18 to 21 years old, were studied. All were within 10% of their ideal weights and had negative family histories of diabetes mellitus and normal oral glucose tolerance tests. The subjects were 14 hours post-absorptive at the time of each study. Their daily diet was constant and contained 300 grams of carbohydrate throughout the study. Each subject served as his own control. The study was divided into two parts: First, a five-week control period during which each subject's baseline response to weekly infusions of 2-DG was established; and second, the acceleration period in which four separate acceleration exposures occurred over a two-week period, with 2-DG infusions immediately after the first (acute) and fourth (chronic) acceleration exposures.

The 2-deoxy-D-glucose solution was prepared in sterile, distilled water and passed through a 45μ Millipore filter into sterile bottles. Small samples of material were cultured on appropriate culture media and were always free of bacterial contamination. Immediately before each infusion, 50 mg. of 2-DG per/kg of body weight were diluted to 100 ml. with normal saline. A large catheter was placed in a brachial vein for the purpose of administration of the 2-DG solution and for obtaining blood samples. After blood samples were taken, 15 minutes before and immediately before the 2-DG infusion, the 2-DG solution was infused at a constant rate via an infusion pump for 30 minutes. Blood samples were obtained 60, 105, and 150 minutes after the start of the 2-DG infusion for the determination of plasma glucose, free fatty acids, cortisol, and serum immunoreactive growth hormone. Urine was collected, from the start of the infusion and for a total of 6 hours, for the determination of urinary epinephrine and norephinephrine. The blood samples were stored in ice, centrifuged under refrigeration, separated, and kept frozen at -15° C. until analyzed. The urines were preserved in hydrochloric acid and refrigerated until the following day, at which time the analyses were performed. Plasma glucose was determined on the Auto-Analyzer by using the potassium ferrocyanide-potassium ferricyanide method (7). Free fatty acids were determined by the method of Dole (8). Plasma cortisol was performed by a simplified fluorometric method (9). Serum immunoreactive growth hormone was done in duplicate by the method of Lau et al. (10). Urinary epinephrine and norepinephrine were determined by the method of Von Euler and Lishajko (11).

The experimental acceleration profile involved a rapid onset acceleration to 2G, holding at 2G for 30 seconds, and then acceleration in 0.5G increments up to a maximum of 4G, with a plateau at the 0.5G stages being held for 30 seconds each. Normally, an end point of peripheral light loss occurred during some portion of the 4G stage, but several subjects were able to continue the full 30 seconds at this stage with no visual impairment. However, the purpose of the exposure was to have a reproducible exposure time - not to expose the subject to a blackout episode in which the run, by necessity, would be halted. The subjects were seated upright in a standard fighter aircraft seat with the inertial vector acting in a head-to-foot direction ($+G_z$ acceleration). They were encouraged to relax as much as possible during the exposure, and intermittently during the run were offered random peripheral and central lights which they turned off with finger control switches. The acceleration period was repeated four times during a two-week interval on each subject. All of the acceleration sessions and subsequent infusions of 2-DG were performed in the forenoon, fasting state. Analyses of variance for randomized groups were done; and, when significant F values were obtained, paired "t" tests between individual groups were obtained. The levels of significance were set at the 0.05 level throughout the study.

Plasma Glucose Resp[illegible]s to Acute and Chronic Acceleration. The mean plasma glucose concentrations before and after the 2-DG infusions, during the control period and after the initial and fourth acceleration sessions, are displayed in Figure 2. No differences in mean fasting plasma glucose concentrations prior to the 2-DG infusions were discernible when control and acceleration data were compared. As compared with the control response, however, significant decreases occurred in the mean plasma glucose response not only at the 60-, 105-, and 150-minute sampling periods following 2-DG administration after the acute acceleration, but also at the 105- and 150-minute period after chronic acceleration.

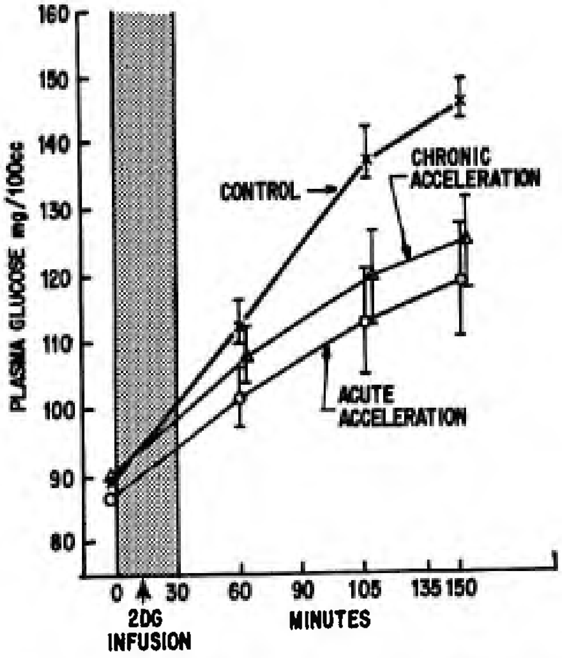

Fig. 2. PLASMA GLUCOSE RESPONSE TO 2DG INFUSION FOLLOWING ACUTE AND CHRONIC ACCELERATION (MEAN ±S.E.M.).

Free Fatty Acid (FFA) Response to Acute and Chronic Acceleration. Mean FFA response to the 2-DG infusion, for the control as well as acute and chronic acceleration, is shown in Figure 3. As in the glucose results, no significant differences occurred in mean fasting FFA's between the three test periods. Moreover, no significant differences were noted between the control and the chronic acceleration mean FFA response to 2-DG administration. However, there was a decreased FFA response after the acute acceleration 2-DG infusion, as compared with the chronic acceleration infusion which was statistically significant at the 150-minute sampling period.

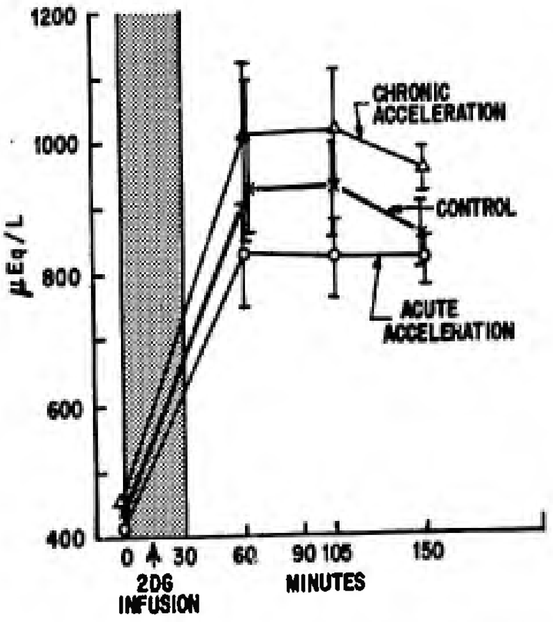

Fig. 3. PLASMA FFA RESPONSE TO 2DG INFUSION AFTER ACUTE AND CHRONIC ACCELERATION. (MEAN ± S.E.M.).

Mean Plasma Cortisol Resp[illegible] to 2-DG Infusion Following [illegible] The mean plasma cortisol responses to the 2-DG infusion are shown in Figure 4. No significant changes were noted in fasting pre-infusion plasma cortisol concentrations, when comparing the control group and the specimens obtained from subjects immediately after the two acceleration sessions but before the 2-DG infusion. Significant differences were noted, however, in mean plasma cortisol response to the 2-DG infusion at the 60-, 105-, and 150-minute periods when the mean control infusions were compared with acute acceleration 2-DG infusion. Mean plasma cortisol elevations during the chronic acceleration, although lower than the control infusions, did not reach significance levels.

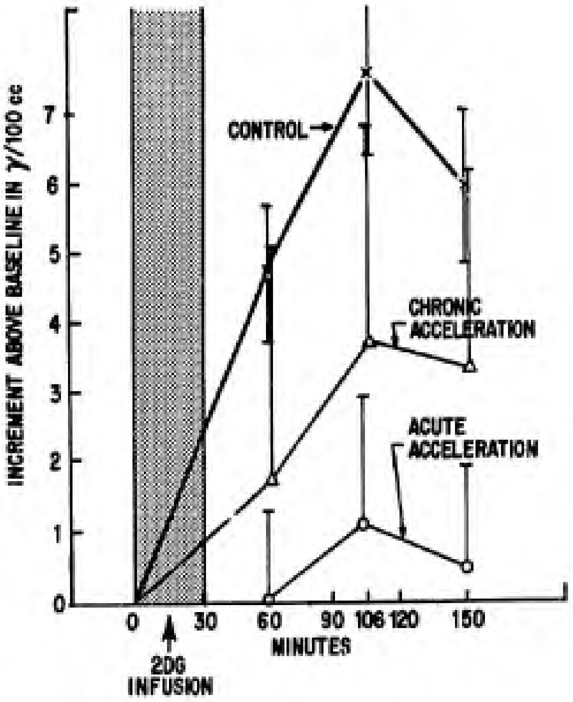

Fig. 4. PLASMA CORTISOL INCREMENT ABOVE THE FASTING POST-ACCELERATION BASELINE FOLLOWING 2DG INFUSION (MEAN ± S.E.M.)

Mean Human Growth Hormone (HGH) Response to 2-DG Infusion. The fasting, pre-infusion mean HGH concentrations, as well as the response to the 2-DG infusions, are illustrated in Figure 5. Although the response in mean fasting HGH - immediately after the fourth acceleration sessions - were decreased when compared with that of the control group, the values are too low to interpret and may not represent a real change. After the 2-DG infusion, the expected rise was noted in plasma HGH concentrations during all of the three infusion periods, without significant differences in the three groups.

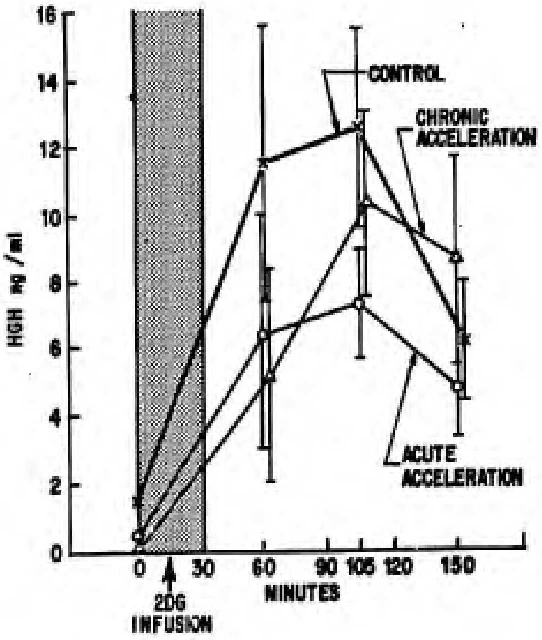

Fig. 5 IMMUNOREACTIVE GROWTH HORMONE RESPONSE TO 2DG INFUSION FOLLOWING ACUTE AND CHRONIC ACCELERATION (MEAN ± S.E.M)

Urinary Epinephrine and Norepinephrine Response Following 2-DG Infusion. Mean urinary epinephrine and norepinephrine excretion values (expressed as gamma/hr) are shown in Figure 6. There was a significantly decreased response in the epinephrine excretion during the 2-DG infusion after the chronic acceleration session as compared with the excretion obtained during the control periods and during the infusion performed after the acute acceleration. No significant differences were noted in norepinephrine excretions after 2-DG infusion during any of the three periods.

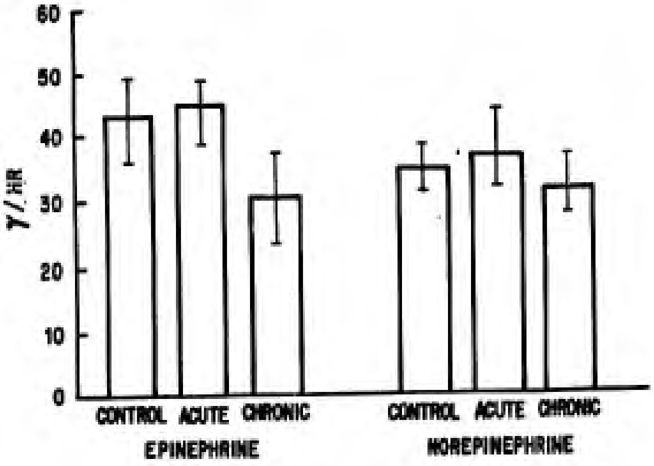

Fig. 6. URINARY EPINEPHRINE AND NOREPINEPHRINE RESPONSE TO 2DG INFUSION FOLLOWING ACUTE AND CHRONIC ACCELERATION (MEAN ± S.E.M.)

DISCUSSION

Although only modest acceleration forces were imposed in this study, there were significant alterations in gluco-regulatory hormone reserve. These alterations would not have been detected if only basal unprovoked hormone levels had been obtained, but did become apparent in response to a subsequent metabolic stress. A summary of the spectrum of biochemical findings and their significance is listed schematically in Figure 7.

	PLASMA GLUCOSE	PLASMA FREE FATTY ACID	SERUM CORTISOL	SERUM GROWTH HORMONE	URINE EPINEPHRINE	URINE NOREPINEPHRINE
ACUTE ACCELERATION	⇩⇩	⇩⇩	⇩⇩	⇩	⇨	⇨
CHRONIC ACCELERATION	⇩⇩	⇨	⇩	⇩	⇩⇩	⇨

Fig. 7. SUMMARY OF MEAN RESPONSE TO 2DG FOLLOWING ACUTE AND CHRONIC ACCELERATION.

⇨ NO CHANGE
⇩ NON-SIGNIFICANT DECREASE FROM CONTROL
⇩⇩ SIGNIFICANT DECREASE

As anticipated, a more substantial decrease in gluco-regulatory hormone reserve resulted from the initial exposure to acceleration stress than from chronic acceleration exposure. The exception was an apparently greater depletion in epinephrine reserve after the chronic acceleration than after the acute (a finding for which we have no ready explanation). The more marked response to acute acceleration can be explained by the lack of experience and anxiety attending exposure to a new stress whereas adaptation to the stress after repeated exposures was reflected in less depletion of the gluco-regulatory reserves.

The normal or only slightly reduced growth hormone response to 2-DG infusion after acceleration suggests either a very large pituitary growth hormone reserve or rapid regeneration of pituitary growth hormone. Since all hormonal levels obtained in this report reflect release rates as well as utilization rates by peripheral tissues, a complete understanding of hormone changes would require measurements of secretory rates.

Glucose is essential for appropriate central nervous system function. Lowered glucose concentrations in the blood result in easy fatiguability, decreased mental performance and, if severe, unconsciousness. These data indicate that the elaborate hormonal regulating processes which normally protect against large swings in blood glucose concentrations are partially compromised after acceleration exposure. These studies point out the importance of considering physiologic reserve when assessing stress tolerance.

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ACKNOWLEDGEMENTS

The authors wish to express their appreciation for the technical assistance and professional guidance of Frode Ulvedal, Ph.D., Colonel William K. Brown and Captain Joel J. Schnure.

FINDINGS ON THE COST OF FLYING TRANSPORT MISSIONS

by

Bryce O. Hartman, Ph.D. (CLNP)
Henry B. Hale, Ph.D. (SME)
USAF School of Aerospace Medicine
Brooks Air Force Base, Texas 78235

ABSTRACT

During the past two years, we have collected large amounts of physiologic and psychologic data from USAF airlift missions flying in an operational configuration. These have included inflight measurements during experimental "double-crew" missions and basic crew missions with staging for crew rest, as well as "following" approximately 125 basic missions using a special workload log. Psychologic analyses have evaluated subjective fatigue, sleep, and crew workload, and the relationship between these and endocrine-metabolic activity assayed via urine. This paper will focus on the "cost" of flying a transport mission in the face of multiple stresses characteristic of the operational environment.

INTRODUCTION

For the past three years, we have been studying flying fatigue and stress for the USAF Military Airlift Command (MAC). The research focused on the C-5, and in particular on crew work rules (e.g., the work/rest cycle) when flying in the double-crew mode, but the scope of the research also encompassed more conventional transport missions. Our most detailed data collection occurred during 7 double-crew missions in the C-141 (55-hour missions) and 7 in the C-5 (75-hour missions, normally). The crews worked on either a short work/rest cycle (4/4 or 5/5) or a long cycle (12/12 or 14/14). Data collection procedures included urine samples analyzed for endocrine-metabolic changes, oral temperature, self-reports on fatigue and sleep, and crew performance ratings by an onboard flight examiner, most of these on a 4-hour basis. Portions of the research were reported to this group last year (1).

Recently we submitted our recommendations to MAC on double-crew operations and on aircrew work rules in general. We recommended medium work/rest cycles (in the range of 8/8 to 12/12) to ensure reasonable inflight sleep periods during double-crew operations. We also recommended longer (24 hour) predeparture crew rest and modified, generally slightly longer postmission rest, in both cases to ensure adequate, normal sleep periods. The evidence to support these recommendations consisted of changes during flight and the recovery curves for each of the several kinds of data we had. We discussed these several measures by referencing the concept of "cost," which the command accepted as reasonable.

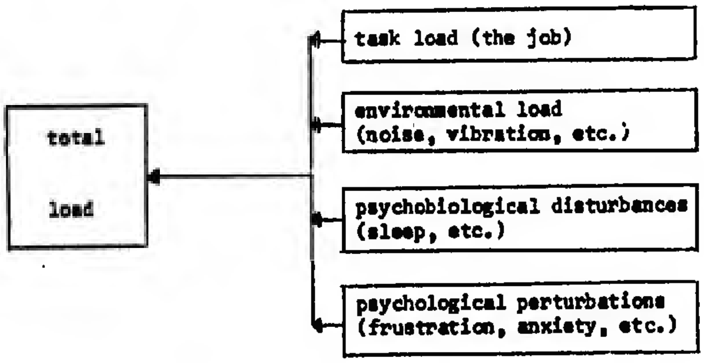
At the USAF School of Aerospace Medicine, we have a continuing program of research on the physiologic "cost" of flying. The basic reasoning is that flight presents to the flyer a complex of factors, some of which act in the manner of stressors, tending to disrupt the dynamic equilibrium (the homeostatic state) that exists normally. It is further reasoned that flight factors of even low intensity may act additively or synergistically. Conceivably, some of these factors have potentiating or facilitating influence for certain others. Subjective fatigue or even performance decrement, for example, may be resultant effects of low-intensity flight factors that act either concomitantly or sequentially.

The reasoning on physiologic "cost" goes further, suggesting that it is possible to delay, lessen, or even prevent certain of the adverse effects of flight by physiologic means, namely, neuroendocrine adjustments. In very experienced flyers, unlike inexperienced flyers, these adjustments appear to be proportionate to the need, showing relationship to the factors of intensity and flight duration. Currently, the USAFSAM research is aimed at testing this assumption more extensively.

In this paper we will attempt to be more systematic regarding "cost." The concept is probably as elusive and resistant to a widely accepted, concrete definition as the concepts of "fatigue" and "stress." As a working approach to "cost" in our research, let us assume the following.

a. A transport mission imposes a complex set of "loads" and/or challenges which induce homeostatic perturbations on the aircrewman.

b. These come from several different sources as follows:



c. The aircrewman responds to an undefined sum of these with physiologic and psychobiologic changes at a level generally commensurate with the total load and usually without compromising his performance on the job. He also requires a finite time to recover (return to "normal" levels) after a mission.

d. Our measures of the crewman's physiologic responses are clearly not direct measures of "cost," but they occur in proportions related to load and show recovery times proportionately related to both the magnitude and duration of the load. Therefore, they are meaningful measures of "cost" in a relative sense, even though we may not be able to specify quantitatively all of the components or even the total load.

e. Specifically, we are proposing here that the responses are proportionate to the load and that the load/cost relationship is reasonably constant. If this is correct, it follows that the responses are proportionate to the cost. We have come to the conclusion, however, that it is vital to identify which responses in our measurement battery reflect this relationship, and to account for each and every response we measure in some way relative to load and cost.

If we can make this rationale convincing, we will be in a better position to interpret our and other's data and to present recommendations to operational commands. We expect the accumulation of evidence to support this rationale to be slow and arduous, but we will start in this paper by presenting our "double-crew" data and then adding to it data from other studies we have conducted.

EXPERIMENTAL FINDINGS FROM C-141/C-5

With this rationale in mind, we will now present the major findings in the C-141/C-5 program which we described briefly at the beginning of this paper.

Crew Performance

There were no major changes in crew performance in either of the two aircraft. There was one set of second order effects (interactions between work/rest cycles and portions of the mission), but the drops in performance were minor and do not bear on this discussion of cost. What is important, however, was the maintenance of mission performance despite the load-induced perturbations. Since flying a transport obviously involves a greater load, and (by our rationale) a greater cost than a day of crew rest, the data from this study offer a good opportunity to examine the nature of the cost.

Oral Temperature

Our findings on oral temperature changes in C-141 double-crew missions were published in mid-1970 (2). We reported a relative hypothermia but with continued rhythmicity and substantial but not complete recovery on the first postmission day of rest. The effects are more pronounced in crew members with the heavier load. The effects were also more pronounced on the short (4/4) work/rest schedule. Selye describes hypothermia as a response to acute stress and others have emphasized the role of sleep disturbance. The data are presented in table I. The hypothermia and the cycling in C-141 data are apparent. The C-5 data are tentative because we are still collating the values. However, it appears that hypothermia occurred to a lesser extent. The C-5 crews had the added stress of frustration resulting from frequent enroute delays, but apparently this was offset by more enroute sleep, as the reader will see shortly. We feel that better sleep accounts for the smaller downward shift, but there is evidence that stress is still present. With regard to recovery, the largest shift toward normal values occurred after the first night of sleep for C-141 crews but only after the second night of sleep for C-5 crews. Apparently stress shifts from frustration were more resistant to reversal than the more conventional flight stresses. Both sets of crews show a stress residual even after three nights of sleep.

TABLE I

Oral Temperature

		C-141		C-5	
		Flt	Recovery	Flt	Recovery
	1000	97.3	97.6	97.9	97.6
	1400	97.4	98.1	98.0	97.7
	1800	97.5	98.4	97.9	97.8
	2200	97.4	98.1	97.6	97.8
	0200	97.0	-	97.5	-
	1000	97.3	97.8	98.2	97.8
Time of Day (Home Base)	1400	97.4	98.2	98.0	98.1
	1800	97.5	98.3	98.2	98.1
	2200	97.5	98.1	98.0	98.0
	0200	97.0	-	97.9	-
	1000	97.2	97.7	97.7	97.9
	1400	97.5	98.0	97.7	98.0
	1800	-	-	98.0	98.1
	2200	-	-	97.7	98.1
	0200	-	-	-	-

Subjective Fatigue

The subjective aspects of fatigue were measured with a self-reporting checklist which yields a score from zero (exhausted) to 20 (refreshed). The scores typically range from 5 to 15 and show a daily rhythm even under nonworking conditions. Our findings from the C-141 flights were published in 1971 (3). We found a significant drop and damping of the rhythm in ratings after day 1 of the mission, and an enhancement of the effects for the more demanding crew positions. The data for both the C-141 and C-5 are shown in table II. The C-5 data (unpublished at this time) confirm C-141 findings except that there was less damping in the rhythm. This probably reflects better inflight sleep. C-5 crews started a bit lower on the scales, but again delays (at the on-load station in this case) probably contributed. With regard to recovery, both sets of crews show a substantial upward shift after the first night of sleep, but there is still a residual after three days.

TABLE II

Subjective Fatigue

	C-141		C-5	
Time of Day (Home Base)	Flt	Recovery	Flt	Recovery
1000	14.0	12.4	10.4	10.6
1400	13.0	12.8	10.3	11.2
1800	12.2	11.4	10.4	10.5
2200	11.2	10.0	9.5	9.3
0200	9.3	-	9.4	-
1000	9.5	13.5	9.1	12.7
1400	9.9	12.1	9.6	12.2
1800	9.9	9.9	9.7	11.6
2200	9.8	10.2	9.4	9.9
0200	9.5	-	8.9	-
1000	9.5	13.5	8.9	13.3
1400	9.3	13.2	9.2	12.4
1800	-	-	9.5	11.0
2200	-	-	9.7	9.8
0200	-	-	-	-

Sleep

Findings on sleep for the C-141 missions were published in 1971 (3, 4). C-5 findings have not yet been published. The data presented in table III show that inflight sleep was reduced and that the reduction was greater when the sleep facility was poorer (C-141). The double-crew data (left and middle columns) suggest a cumulative sleep debt from which crew members recovered by sleeping more after the mission. The C-5 data for recovery day 1 reflected the added insult of frustration, mentioned earlier. However, the data from the right column for single crew missions, particularly on recovery days, indicate that the mission load itself is the primary factor in increased postmission sleep, since single crews have the opportunity to minimize a sleep debt during crew rest at stages. It would appear to us that poor enroute sleep is a primary aggravator of enroute fatigue and physiologic stress responses but that mission load in general is the primary factor in postmission sleep. We also hypothesize that in turn postmission sleep is the primary factor in recovery from mission perturbations in physiologic and psychobiologic mechanisms. It is clear that the situation is far from simple.

TABLE III

Sleep**

		C-141 double	C-5 double	C-141 basic
Predeparture		(7)*	9.8	6.8
Enroute	1	1.8	5.4	7.4
	2	6.1	6.0	7.2
	3	5.9	6.2	7.8
	4			7.8
	5			7.5
Recovery	1	9.8	11.1	9.9
	2	9.3	8.8	9.2
	3	8.9	8.9	8.9

*based on crew narrative reports. **hours

Physiologic Findings

The measures just discussed were, grossly, psychobiologic. We will turn now to the endocrine-metabolic measures. Table IV compares physiologic costs in four different crew positions. Bear in mind that each value is the mean of data collected for two men in six flights, each of which began at a standard time of day. With the starting times standardized, and with urine specimens collected at 4-hour intervals starting at the end of the 2nd hour after departure and ending at the 50th hour, the data for the six different flights were synchronous. Circadian periodicity was therefore not an obscuring or distorting factor. Also bear in mind that all urine values have been referred to Eastern Standard Time, the time to which these flyers were physiologically entrained.

TABLE IV

Physiologic Cost in Relation to Crew Position

Physiologic Index	Period	CREW POSITION			
		AC	CP	NAV	FE
Epinephrine	Flight	169	145	137	125
	Postflight	105	81	85	95
Norepinephrine	Flight	158	111	124	109
	Postflight	104	85	77	96
17-OHCS	Flight	122	117	100	106
	Postflight	76	73	65	76

Mean values for data obtained at 1000, 1400, 1800, and 2200 hours. Each value represents two men studied during six flights. All values have been expressed as percent of respective control values. Control subjects were flyers who were studied on a day of nonflying duty.

All values in table IV have been expressed as percent of control values for two reasons. First, this procedure in effect eliminates the purely circadian variations; second, the use of a common scale enables cross-comparisons of these particular indices.

These data, as organized, bring out the gradation in physiologic cost that relates to crew position. In all three respects the Aircraft Commander position was the most costly. Note also that residual effects were evident for the Aircraft Commander group, at least with respect to epinephrine and norepinephrine for the postflight values slightly exceeded the respective control levels. The postflight values for the remaining groups all fell considerably below the respective control levels. Finally, note that there was gradation with respect to the physiologic indices, epinephrine for all four groups consistently outranking the respective norepinephrine and 17-OHCS values. This is interpreted as indicating that adrenomedullary sensitivity to flight factors exceeded sympathetic nervous system sensitivity, which in turn exceeded adrenocortical sensitivity. The finding that the flight-induced adrenocortical elevation was never of great magnitude leads us to suggest that physiologic reserves remained relatively high.

Table V compares results for the portions of the flight period that corresponded to daytime and nighttime at the flyers' home base. Data obtained at 1000, 1400, 1800, and 2200 hours were averaged to give the so-called "diurnal" values for epinephrine, norepinephrine, and 17-OHCS; those obtained at 0200 and 0600 hours were averaged to give the so-called "nocturnal" values.

In all three respects, the nocturnal costs exceeded the diurnal costs. On the basis of diurnal catecholamine data, a slight decrease in cost was indicated during the second day, but this trend was not evident in the nocturnal catecholamine data. The 17-OHCS data indicate increased cost in both parts of the second day.

TABLE V

Day-Night Differences in Flying Cost

Physiologic Index	Day No. 1		Day No. 2	
	Diurnal Portion	Nocturnal Portion	Diurnal Portion	Nocturnal Portion
Epinephrine	160	175	126	179
Norepinephrine	133	152	124	169
17-OHCS	104	163	118	202

Each value is expressed as percent of a control value and represents eight men studied in six different flights. Diurnal data were obtained at 1000, 1400, 1800, and 2200 hours; nocturnal data were obtained at 0200 and 0600 hours.

Table VI shows physiologic co[illegible]ta in relation to flight duration. These values all represent 1000 data for the 8-man group. The earliest determination was made at the end of the second hour of flight, and it is believed to reflect preflight values primarily, since urinary changes lag 2 or more hours behind changes in neuroendocrine functions. The middle determination represents 26 hours of flying while the final determination represents 50 hours.

TABLE VI

Flying Cost in Relation to Flight Duration

Physiologic Index	Elapsed Time		
	2 hours	26 hours	50 hours
Epinephrine	231	137	154
Norepinephrine	147	127	147
17-OHCS	101	95	103

Each value is the mean for eight men studied in six flights at 1000 hours. Each mean has been expressed as percent of a control mean.

The highest catecholamine values appeared at the earliest time. This result is interpreted as indicating that there was carry-over from the preflight period, a time of physiologic unsteadiness. The lower catecholamine values at the 26th hour denote physiologic settling, and the gain in catecholamine excretion over the final 24 hours indicates that, in this final period, flight duration had weak positive influence. Adrenocortical activity, in contrast to sympathoadrenomedullary activity, tended to remain constant, approximating the control level at all three times.

Table VII compares costs in two flights. The same double crew flew both flights, and the itineraries were the same. For unknown reasons extreme fatigue developed in one flight but not in the other. The different patterns of change in epinephrine excretion are of interest. Evidently, the physiologic cost at 26 hours in the abnormal flight was unduly high; consequently, this led to a decline which is considered an inappropriate response suggestive of impending exhaustion. Norepinephrine also indicates relatively high costs at the 26th and 30th hours, followed by a decline. In both flights, 17-OHCS output rose at the final time, thereby indicating exorbitant cost.

TABLE VII

Flying Cost in Normal and Over-Fatiguing Flights

Physiologic Index	Flight	Elapsed Time		
		26	30	34
Epinephrine	Normal	48	116	131
	Abnormal	258	181	102
Norepinephrine	Normal	55	127	129
	Abnormal	199	214	108
17-OHCS	Normal	93	87	173
	Abnormal	108	98	152

Each value represents the same eight crew members and is expressed as percent of control value.

Table VIII shows physiologic cost in relation to aircraft type. These data were obtained from different crews, so a firm conclusion is impossible. Still, the catecholamines for the C-5 crew indicate a gaining cost with time, a pattern of change opposite to that for the C-141 crew. Both crews show slight gains with time for 17-OHCS.

TABLE VIII

Physiologic Cost in Relation to Aircraft Type

Physiologic Index	Day	Aircraft Type	
		C-141	C-5
Epinephrine	1	146	118
	2	112	152
Norepinephrine	1	135	100
	2	121	142
17-OHCS	1	100	115
	2	118	122

Each value (expressed as percent control) represents eight crew members. The different aircraft were flown by different crews.

BACKGROUND STUDIES

Findings in earlier studies are pertinent at this point. When this research program began, we used only plasma cortisol determinations to estimate the physiologic "cost," and evidence was obtained that suggested that multi- and single-place aircraft do not present equally intense stimuli. On the basis of results from two studies (5, 6) it appeared that (a) the type of aircraft was a factor in determining the "load" or intensity aspect and (b) that the factors of intensity and time acted in reciprocal manner when inducing physiologic compensation. In support of these points, we found that 44 B-52 crew members showed evidence of adrenocortical stimulation when examined at the end of daytime flights lasting 9 to 12 hours, the postflight mean plasma cortisol concentration amounting to 150% of the preflight mean. In turn, 43 pilots of F-100 aircraft, when examined at the end of daytime training flights of only 50 minutes duration, showed about the same gain in plasma cortisol as was noted in the B-52 study, whereas F-100 pilots who flew 2295 nautical miles over a period of 6 hours had an average plasma cortisol level that amounted to 260% of the average for groups of controls (flyers who were studied on a day of nonflying duty). For this group of pilots, we also used pre- and postflight urine specimens, analyzing for epinephrine and norepinephrine, thereby assessing activity levels in the adrenal medulla and the sympathetic nervous system. The mean urinary epinephrine and norepinephrine values amounted to 512% and 290% of the respective control values.

SUMMARY

In conclusion, what we see in the data presented to this point is as follows: (a) physiologic activation in response to the challenge, accompanied by elevations in the excretion of selected endocrine products, both proportionate to the load imposed; (b) a typical signal of stress, hypothermia, which may be adaptive; (c) degraded sleep in flight, with the adequacy of the sleep facility itself playing an important role; (d) interference with recovery from subjective fatigue despite sleep periods; (e) aggravation of a, b, and d by partial sleep deprivation; (f) perturbations in the cyclic characteristics of those mechanisms involving rhythmicity; (g) increased postmission sleep in general proportion to the total load; (h) progressive recovery during postmission crew rest, facilitated by increased postmission sleep; and (e) some extra-rhythmic oscillation around "normal" values as recovery continues. Most of this is consistent with stress physiology in general and by itself constitutes one statement of the cost of flying a transport mission. Some persons may prefer to reserve the term "cost" for such things as "oxygen uptake," "substrate utilization," etc. While such "costs" would be of interest, they are not easily measured under field conditions.

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DISCUSSION

HOWARD

Costs may be expressed in relative terms, but it is more important to know whether they can be met without causing bankruptcy. How will your studies measure the total amount of physiological currency available?

HARTMAN

This is a question of considerable significance. In our studies at USAFSAM, we have worked (with some difficulty) to the point where we feel somewhat confident in labeling a stress complex as "mild," "moderate," or "severe," depending on excretion rates across 15-20 field experiments. We can't go further until we develop a numerical scale with validated anchor points at least at the top and bottom. Dr. Lecocq, in his paper this morning, suggested that stress physiologists anchor the top of the scales by provoking an artificial maximal stress response by chemical means (in his study injecting 2-D G). We intend to follow that lead for the next couple of years. We assume that the bottom of the scale is the normal circulating level of any specific biochemical material but modified by, at least, circadian and circannual rhythms, geographical/climatologic factors, and individual differences. I feel that this Panel should put special effort into defining the problems associated with this scale and facilitating research on it in all NATO nations.

MODIFICATIONS PHYSIOLOGIQUES AU COURS DE VOLS OPERATIONNELS DE LONGUE DUREE

par

Médecin en Chef de 2ème classe R. AUFFRET
Centre d'Essais en Vol
91 - Brétigny - sur-Orge
FRANCE

SOMMAIRE

Des vols de longue durée sont effectués lors des tirs de fusée, par les avions chargés de la surveillance et de la maintenance du champ de tir. Les caractéristiques opérationnelles de ces vols les rendent particulièrement stressants. En effet, il s'agit de vols de longue durée réalisés à basse altitude sur l'océan. Ils nécessitent une attention et une précision très grandes de la part de l'équipage. De plus, les conditions climatiques de l'habitacle sont mauvaises à cause de la température élevée liée au dégagement de chaleur de l'électronique du bord.

Au cours de ces vols les modifications physiologiques suivantes ont été notées :

- l'augmentation de la fréquence cardiaque dans les phases du vol les plus délicates,
- l'augmentation de l'excrétion des 17 cétostéroïdes urinaires, des catécholamines urinaires et de la réaction de DONAGGIO,
- l'augmentation de la glycémie.

Comme la plupart des auteurs, nous avons ainsi montré que certaines fonctions métaboliques et endocriniennes sont sensibles au vol et qu'il existe des rapports entre ces fonctions et la fatigue engendrée par le vol. Il est cependant difficile de déterminer le degré de fatigue et de prévoir les limites de la performance humaine car il n'existe pas de corrélation directe entre l'intensité du stress et celle de la fatigue. Cette réaction est en effet strictement individuelle ; elle dépend du tempérament, de la faculté à effectuer le travail dans des conditions difficiles, de l'adaptation, ainsi que des qualités mentales et physiques du sujet.

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INTRODUCTION

La fatigue que connait le personnel navigant pendant les vols de longue durée est un phénomène connu et de nombreux auteurs ont décrit les modifications physiologiques qui l'accompagnent.

Il a été ainsi montré que certaines fonctions métaboliques et endocriniennes sont sensibles au vol et il semble exister des rapports étroits entre ces fonctions et la fatigue engendrée par le vol.

Il est cependant difficile de déterminer le degré de fatigue, car il n'y a pas de corrélation directe entre l'intensité du stress et la fatigue obtenue. Cette réaction en effet est strictement individuelle, elle dépend du tempérament, de la faculté à effectuer le travail, de l'adaptation et des qualités mentales et physiques du sujet.

CONDITIONS OPERATIONNELLES DE L'EXPERIMENTATION

Une évaluation physiologique des effets de vol de longue durée a été entreprise sur les équipages des avions DC 7 dit AMOR, c'est à dire "Avions de Mesure et d'Observation au Réceptacle". Ces avions ont été spécialement équipés pour la réception des émissions de télémesure des engins Sol-Sol Balistique Sol (SSBS) et Mer Sol Balistique Sol (MSBS) dans la deuxième partie de leur trajectoire et pour le repérage, avec la meilleure précision possible, des points d'impact de ces engins dans l'océan Atlantique au large des Açores.

Pour remplir cette mission opérationnelle, les avions DC 7 C classiques ont été modifiés. Les modifications extérieures comportent essentiellement l'adjonction de deux radomes de grandes dimensions et de coupoles d'observation. Intérieurement l'habitacle a été changé pour permettre le travail des équipes de navigation et d'expérimentation. Les moyens de navigation autonome de l'avion sont en effet très complets : en plus des systèmes de navigation classiques, il existe un système de navigation autonome très élaboré avec radar Doppler, centrale à inertie et même, à titre de sécurité, récepteur LORAN A et LORAN C. L'électronique d'enregistrement est très importante avec horloges de précision, enregistrements magnétiques, télémesures... etc... Tous ces instruments sont réunis dans la partie avant du fuselage qui est en fait le lieu de travail de 8 à 10 ingénieurs, expérimentateurs, navigateurs et radaristes.

La partie arrière du fuselage ressemble plus à un avion de transport classique avec sièges habituels, c'est aussi un lieu de repos éventuel avec couchettes et coin pour la prise du repas.

Le poste de pilotage n'a guère été modifié, mais l'autonomie de l'avion a été portée à plus de 24 heures par l'adjonction de réservoirs de carburant supplémentaires qui occupent la partie centrale de la cabine.

Le réceptacle des tirs se situe dans une zône située à 500 kilomètres des Acores. L'avion se rend généralement dans cette zône quelques heures avant le tir, après avoir recalé sa navigation par passage à la verticale d'un point géodésique connu soit visuellement, soit radioélectriquement, et après avoir mis avec précision à l'heure ses différentes horloges. Il réalise alors sur la zône prévue une mission de surveillance du réceptacle avec observation de tous les bateaux commerciaux ou de pêche, indiscrets ou curieux.

Avant le tir, l'avion se place entre l'impact prévu et la zône la plus favorable de réception de la télémesure. Il devra au moment du lancement passer en un endroit donné, à une heure précise, afin de pouvoir localiser le point d'impact. Ces vols ont des durées variant suivant les tirs, de 7 à 18 heures.

Ces diverses caractéristiques opérationnelles rendent ces vols longs et fatiguants. En effet, il s'agit de vols réalisés à basse altitude dans des conditions météorologiques parfois difficiles avec turbulence parfois importante.

La climatisation avion, malgré des systèmes supplémentaires n'est pas toujourssuffisante pour conserver une température acceptable d'autant que la volumineuse installation de mesure implantée dans la cabine produit beaucoup de calories superflues. Il est fréquent d'avoir de grosses différences thermiques dans la cabine. Lors des campagnes estivales, la température atteint couramment 27 à 30° centigrades au poste de pilotage avant, 32 à 35° dans la partie cabine où sont les instruments de mesure, 20 à 25° dans la partie cabine arrière qui comprend la salle de repos des équipages. L'hygrométrie est variable suivant les conditions du vol : voisine de 95 % parfois lors de vols à basse altitude sur la mer ; elle est plus sèche lorsque les vols ont lieu entre les niveaux de vol 50 ou 150 où elle est généralement voisine de 50 %.

ETUDE PHYSIOLOGIQUE

L'étude physiologique a été réalisée au cours de 11 vols d'entraînement et non pas lors de tirs réels. 10 vols eurent des durées comprises entre 7 et 12 heures 30. Un onzième vol un peu particulier dura 24 heures sans escale. Ce vol retiendra plus particulièrement notre attention. Le décollage eut lieu à 15 heures locales, l'atterrissage à 15 heures le lendemain. Aux 24 heures de vol il faut donc pratiquement ajouter 7 heures de travail au sol car l'ensemble de l'équipage commença sa journée de travail à 8 heures locales comme tous les jours. Au cours de ce vol, les enregistrements physiologiques furent effectués sur deux pilotes, deux navigateurs et un radariste. L'équipage se reposa entre 1 heure et 3 heures au cours de la mission. En particulier, un pilote ne prit qu'une heure de repos avec $\frac{1}{2}$ heure de sommeil au cours de l'ensemble de la mission. Il sera d'ailleurs celui qui aura les plus grosses variations physiologiques.

Dans ces missions, les paramètres physiologiques suivants ont été étudiés :

- fréquence cardiaque
- élimination urinaire des 17 cétostéroïdes
- élimination urinaire de la mucoprotéine (réaction de Donaggio)
- élimination urinaire des catécholamines.
- glycémie (au cours du vol de 24 heures).

L'expérimentation a porté au total sur une dizaine de navigants : pilotes, navigateurs et radaristes. L'âge moyen de ces membres d'équipage est d'environ 37 ans; le plus jeune a 30 ans, le plus âgé 44 ans.

1 - Fréquence cardiaque

Principe

La fréquence cardiacue est obtenue à partir de trois électrodes placées sur le thorax des sujets. Le signal cardiaque QRS est amplifié, puis normalisé afin de permettre le dépouillement automatique à l'aide d'un calculateur analogique, comme dans les travaux de KALSBEEK et de HOWITT, nous analysons la fréquence cardiaque instantanée et la variation de l'arythmie simusale, c'est à dire la variabilité de la période entre les battements cardiaques par la mesure de la différence de durée entre deux périodes cardiaques consécutives.

En effet, nous pensons que la diminution de la variabilité de la durée de la contraction cardiaque, c'est à dire la diminution de l'arythmie sinusale est un bon paramètre physiologique de la charge mentale. La charge mentale est ici définie comme le nombre de décisions à prendre par unité de temps, c'est à dire la quantité d'informations à traiter par unité de temps.

Résultats

Sur la figure 1 sont représentées les valeurs de la fréquence cardiaque trouvées chez les pilotes pour différentes phases de vol. Les valeurs les plus importantes sont rencontrées à l'atterrissage, où la fréquence cardiaque a pu atteindre chez un pilote le chiffre de 165 pulsations/minute après un vol de 24 heures.

Plus généralement dans cette phase de vol, la fréquence cardiaque est trouvée aux environs de 115-120 pulsations par minute au moment du toucher des roues alors que lors du vol en palier sans occupation particulière la moyenne de la fréquence cardiaque de nos pilotes était aux alentours de 75 pulsations par minute.

Le terme "verticale" utilisée en abscisse sur la figure 1 désigne le passage à la verticale d'une tâche de fluorescence - simulant le point d'impact d'un engin - à la suite d'un alignement précis, donc d'un pilotage nécessitant une attention soutenue. La verticale où la fréquence cardiaque est plus élevée correspond aux passages à plus basse altitude au cours desquels il est évidemment plus difficile de visualiser le point de passage.

Les figures (2, 3 et 4) montrent les fréquences cardiaques du pilote lors du vol de 24 heures. Après avoir accumulé la fatigue d'un vol de 24 heures avec seulement 1 heure de repos il se présenta pour un atterrissage rendu délicat par un très fort vent (45 Kts) avec fortes turbulences. Sur la figure (3) on voit que sa fréquence cardiaque instantanée est bloquée aux alentours de 150 pulsations/minute pour atteindre 165 au toucher des roues. L'arythmie sinusale a pratiquement disparu (fig. 3).Fréquence et arythmie sinusale reprennent une allure plus classique après l'atterrissage lors du roulage (figure 4). Cet enregistrement est réalisé 2 minutes après le toucher des roues.

2 - Analyse des urines

La récolte des urines commençait au décollage et se terminait dans la ½ heure suivant l'atterrissage. Un bocal différent était affecté à chaque collection d'urine.

Cependant dans le vol qui dura 24 heures, les urines étaient réunies dans 4 récipients. Le décollage eut lieu à 15 heures. Pour chaque sujet,

le bocal 1 recueillit les urines jusqu'à 17 h 30
" 2 " " " 23 h 00
" 3 " " " 6 h 00
" 4 " " " 15 h 00

Les examens suivants ont été effectués :

- Réaction de Donaggio
- Dosages de catécholamines urinaires
- Dosages des 17 cétostéroïdes urinaires

Ces divers produits métabolites ont des taux variables suivant la diurèse et le rythme nycthéméral. La comparaison est possible pour le vol de 24 heures mais plus délicate pour les vols d'une durée inférieure (10 vols entre 7 heures et 12 h 30). A titre indicatif les mêmes dosages ont été effectués sur 4 navigants au sol lors d'une journée de travail sans vol.

2.1. Réaction de Donaggio

Principe et signification

La réaction de Donaggio est basée sur le fait que certains colorants thiaziniques (bleu de toluidine, bleu de méthylène, thionine) en solution aqueuse, précipitent en présence de molybdate d'ammoniaque. Mais si l'on ajoute de l'urine à la solution d'un des colorants ci-dessus avant de la mettre en présence de molybdate d'ammoniaque, on a un précipité plus ou moins diminué ou même inexistant. Ce phénomène d'obstacle à la précipitation, décrit par Donaggio, est dû à une substance contenue dans l'urine à un taux de concentration plus ou moins important et qui est une mucoprotéine. Cette "substance d'obstacle" fût étudiée par de nombreux auteurs (Falet, Albeaux Fernet, Bugard, Tayeau).

Tous ces auteurs ont montré qu'il y avait une relation positive entre l'excrétion de mucoprotéine responsable du "phénomène d'obstacle" et la fatigue musculaire. Il a été prouvé que l'effort musculaire augmente l'excrétion de cette "susbstance d'obstacle".

Cette mucoprotéine semble provenir du plasma à la suite d'une réaction d'alarme ou d'une agression qui entraîne une profonde altération de la substance fondamentale du tissu conjonctif. Après un processus de dégradation, le rein élimine alors une mucoprotéine urinaire qui est responsable du "phénomène d'obstacle" découvert par DONAGGIO, et qui résulte en grande partie de l'altération du tissu conjonctif en réaction à un stimulus tel que la fatigue musculaire.

Plusieurs auteurs ont pensé que l'on pouvait valablement inclure la réaction de Donaggio dans une batterie de tests, destinés à quantifier dans une certaine mesure la fatigue, déjà décelée par un examen clinique. Les travaux de FALET ont mis en évidence l'intérêt de l'emploi de la réaction de Donaggio en Aéronautique pour le diagnostic de la fatigue du pilote : que cette fatigue résulte d'un ensemble de facteurs propres au milieu Aéronautique (bruits, vibrations, accélérations, etc...) ou de facteurs non spécifiques tels que la fatigue statique musculaire due aux vols de longue durée, les troubles du sommeil et des rythmes de vie, les variations thermo-hygrométriques, etc.... Tous ces facteurs peuvent être susceptibles d'entraîner une élévation de l'excrétion de la mucoprotéine urinaire.

Résultats

La méthode de dosage employée est la technique de FALET avec laquelle les résultats normaux sont N = 175 mg ± 34 par 24 heures. L'ensemble des résultats de cette excrétion de mucoprotéine urinaire figure sur les tableaux 1 et 2. Il ne peut être question de faire une exploitation statistique de ces chiffres. Néanmoins les valeurs de l'excrétion rapporté aux volumes dúurine sont plus importantes dans les phases de vol que lors du travail au sol. Ces résultats sont en accord avec les constatations de FALET et DUKES-DOBOS.

Dans le vol de 24 heures le pilote et le navigateur qui se reposèrent le moins arrivèrent à des totaux respectifs de 720 mg et de 686 mg. Tableaux 7 et 8.

2.2. Cétostéroïdes urinaires

- Principe et signification

Depuis la dernière guerre mondiale, un grand nombre d'auteurs ont montré que la réponse au stress chez les aviateurs correspondait à une augmentation du taux d'excrétion des 17 cétostéroïdes urinaires. Cette augmentation semble proportionnelle à la durée du vol et à l'expérience professionnelle des équipages.

Les 17 cétostéroïdes urinaires sont principalement d'origine androgène, c'est la raison pour laquelle certains auteurs préfèrent doser les 17 hydroxycortistéroïdes qui représentent plus fidèlement la production du cortisol et des hormones d'origine surrénalienne, qui sont les meilleurs témoins du stress.

Ces divers dosages montrent une augmentation de l'excrétion urinaire. Pour MARCHBANKS (1958) HALE (1968), cette augmentation est due au stress lié à la mission, au niveau de responsabilité individuelle, mais aussi à la durée du vol et à l'horaire de la mission. La modification est plus importante si le cycle normal du sommeil est contrarié.

- Résultats

La technique de dosage est celle de CAHAN, SALTER et JAYLE qui est basée sur la réaction de ZIMMERMANN. Les chiffres normaux obtenus par le laboratoire pour des adultes males sont N = 13,5 mg/24 heures ± 2,1. Les tableaux 3 et 4 donnent les résultats des vols de durée moyenne et leur exploitation est difficile. Les taux d'augmentation sont comparables à ceux obtenus lors de petit stress biologique ou psychophysiologique de la vie courante.

Par contre, nous pouvons dire que l'élimination des 17 cétostéroïdes urinaires a augmenté sensiblement chez les cinq membres d'équipages lors du vol de 24 heures (tableau 8), principalement chez le pilote qui accomplit l'essentiel du travail au cours de cette mission.

2.3. Catécholamines urinaires

- Principe

Les catécholamines urinaires représentent l'ensemble des substances à activité sympathicomimétique éliminées dans les urines, c'est à dire essentiellement adrénaline et noradrénaline. Leur élimination est augmentée en cas de stress ou de stimulation du système nerveux sympathique. Il semble que l'adrénaline urinaire provienne avant tout de la médullo-surrénale et la noradrénaline urinaire des nerfs sympathiques puisqu'après destruction des surrénales l'élimination urinaire d'adrénaline diminue, mais pas celle de noradrénaline.

- Résultats

Le dosage des catécholamines a été effectué par la technique de BURNS et FIELD dont les résultats normaux sont dans notre laboratoire N = 354 γ/24 heures ± 52. Au cours de nos vols l'élimination des catécholamines s'est accrue par rapport aux témoins sol.

3 - Glycémie

-Principe

La régulation du glucose sanguin chez l'homme normal fait intervenir un certain nombre de facteurs visant en fonction de l'apport glucidique et par la glycogénolyse et la glycogénèse à maintenir la glycémie à un niveau correspondant aux besoins de la consommation glucidique de l'organisme.

Des facteurs métaboliques et hormonaux agissent en énergie sur les divers processus de production et d'élimination du glucose sanguin.

Si l'insuline a une action générale hypoglycémiante par des impacts multiples sur le foie, le tissu adipeux et dans une faible mesure le cerveau, inversement, les cathécholamines, le cortisol, le glucagon, l'hormone somatotrope et d'autres facteurs encore mal définis ont des propriétés hyperglycémiantes. Leur zône d'action est différente suivant la nature de l'hormone. Cela peut être une augmentation de la glycogénolyse ou de la glyconéogénèse, une augmentation de l'absorption intestinale du glucose, ou bien une diminution de l'insulinémie et de la captation périphérique du glucose.

On observe aussi une augmentation de la lipolyse. On pense que la réaction de ces hormones hyperglycémiantes et lipolytiques est coordonnée par la présence de cellules glucosensibles qui ont été individualisées au niveau du diencéphale.

Ainsi, dans toutes les circonstances correspondant à une aggression pour l'organisme, ce dernier réagit par une sécrétion de facteurs hormonaux visant à amener son potentiel énergétique à un niveau tel qu'il puisse faire face aux conditions nouvelles dans lesquelles il se trouve placé. Cette situation entraîne en particulier une augmentation de la glycémie par la mise en jeu des facteurs hormonaux régulant les mécanismes d'apport et de disparition du glucose.

- Résultats

Le dosage de la glycémie effectué au cours du vol de 24 heures est un dosage colorimétrique à l'orthodianisine appliquée en microméthode. Par cette technique, les résultats normaux sont : N = 780 mg/litre ± 140 chez le sujet à jeun .

Au cours du vol de 24 heures, seul vol où ce type de dosage fut réalisé, le prélèvement de sang se faisait à 11 heures du matin par piqure au niveau de la pulpe du doigt. Ce prélèvement avait donc lieu 20 heures après le décollage et entre 5 heures ½ et 6 heures après la prise du petit déjeuner à bord. Ces chiffres peuvent être comparés sur le tableau 8 avec les dosages de glycémie réalisés chez les mêmes sujets suivant le même horaire la veille du vol. Les chiffres du glucose sanguin sont augmentés pour tous les sujets en vol.

Ces constatations sont à rapprocher des travaux de MEYER qui étudia la glycémie de pilote d'avions de haute performance. Après le décollage il constate dans la plupart des cas une augmentation du glucose sanguin.

CONCLUSION - DISCUSSION

Au cours de ces vols de longue durée l'ensemble de l'impression subjective de fatigue décrite par les équipages est confirmée par les données biologiques enregistrées. Cependant, si la fatigue du personnel navigant pendant les vols de longue durée est objectivée par un certain nombre d'altérations physiologiques, il est certainement impossible d'établir des corrélations précises entre telle modification métabolique, endocrinienne, physiologique et le degré de la fatigue ou de la charge de travail à court terme. Le petit nombre de mesures réalisées dans cette expérimentation empêche toute généralisation statistique hative.Néanmoins, ces modifications sont en accord avec les principales données de la littérature. De plus, les données physiologiques restent toujours difficiles à exploiter car les paramètres biologiques étudiés sont soumis à des variations individuelles importantes et à des modifications très sensibles au cours du rythme nycthéméral. Ainsi, par exemple, la mucoprotéine urinaire est basse le matin ; elle augmente dans le courant de la journée et est au maximum au cours de la nuit. A l'opposé, les stéroïdes urinaires ont un rythme inverse : ils suivent en cela les corticostéroïdes sanguins dont les taux peuvent être 4 fois plus élevés le matin que le soir.

Il reste cependant logique de penser que certains facteurs, tels que la durée du vol, le degré de difficulté de la mission ou les conditions de l'environnement propres à chaque vol exercent une influence complexe qui crée l'apparition de modifications physiologiques concommittantes de la fatigue.

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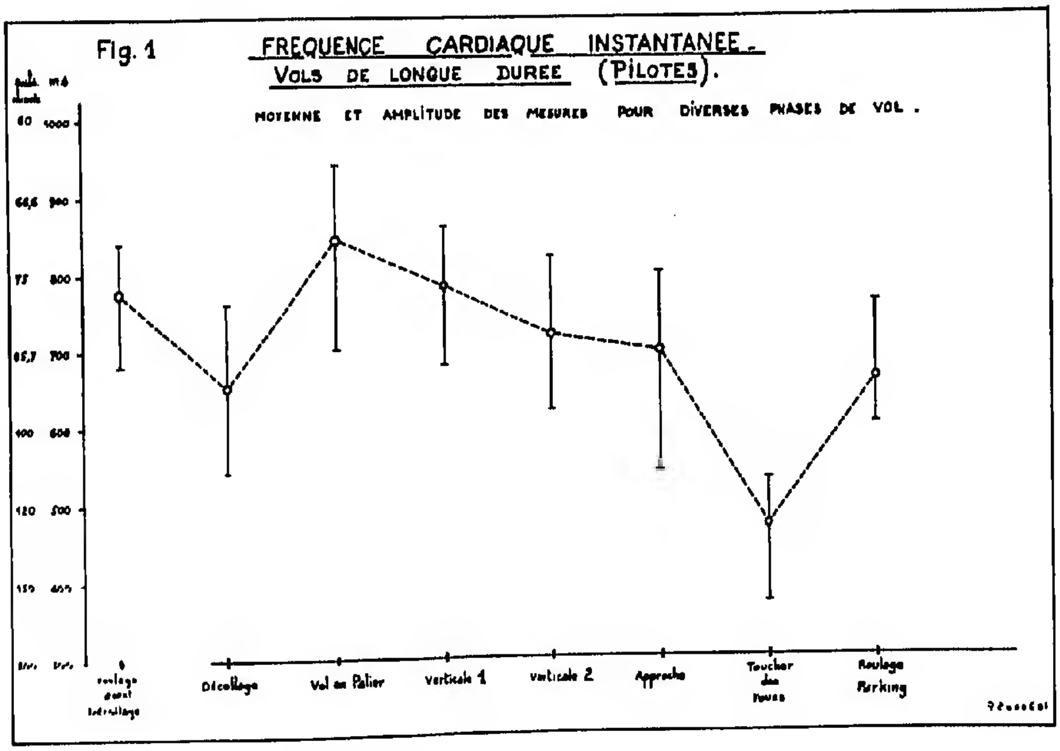
Fig. 1 FREQUENCE CARDIAQUE INSTANTANEE. VOLS DE LONGUE DUREE (PILOTES).

MOYENNE ET AMPLITUDE DES MESURES POUR DIVERSES PHASES DE VOL.

Fig. 2 DECOLLAGE (VOL 24 HEURES)

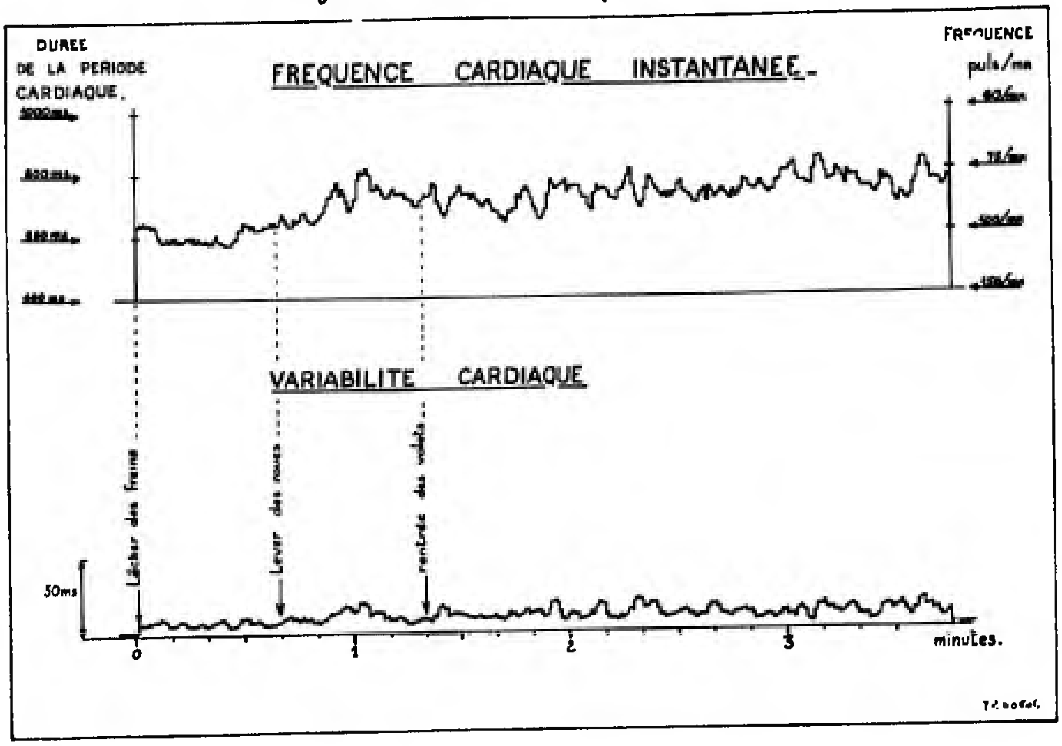

Fig. 3 ATTERRISSAGE (VOL 24 HEURES)

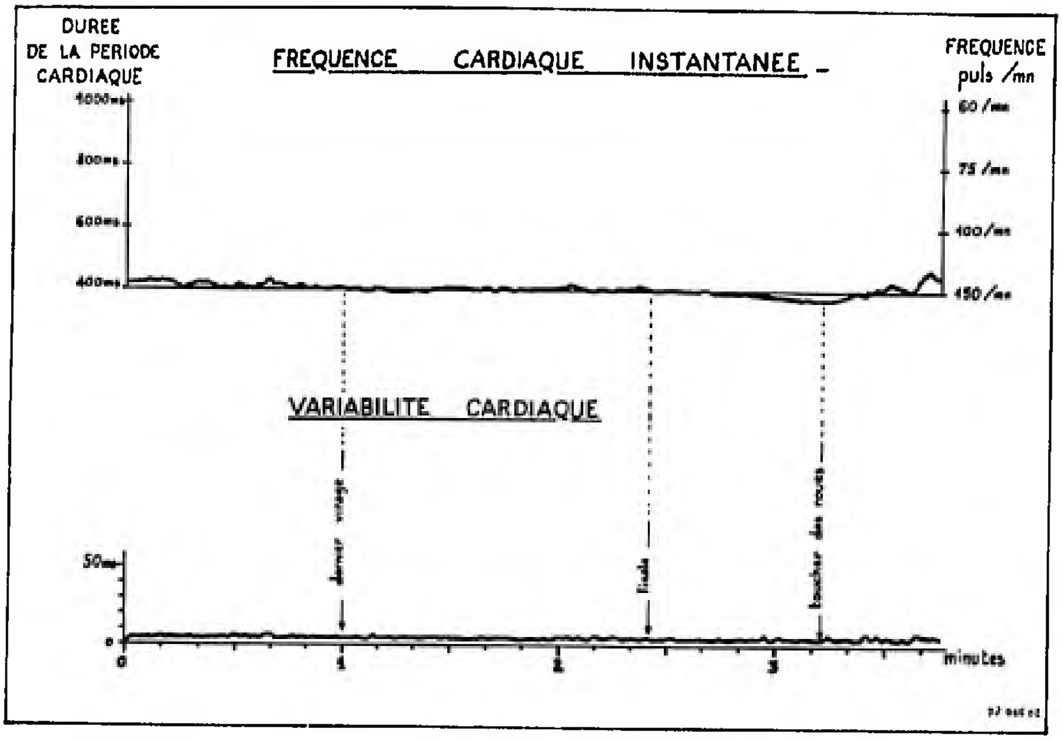

Fig. 4 ROULAGE APRES ATTERRISSAGE (VOL DE 24 HEURES)

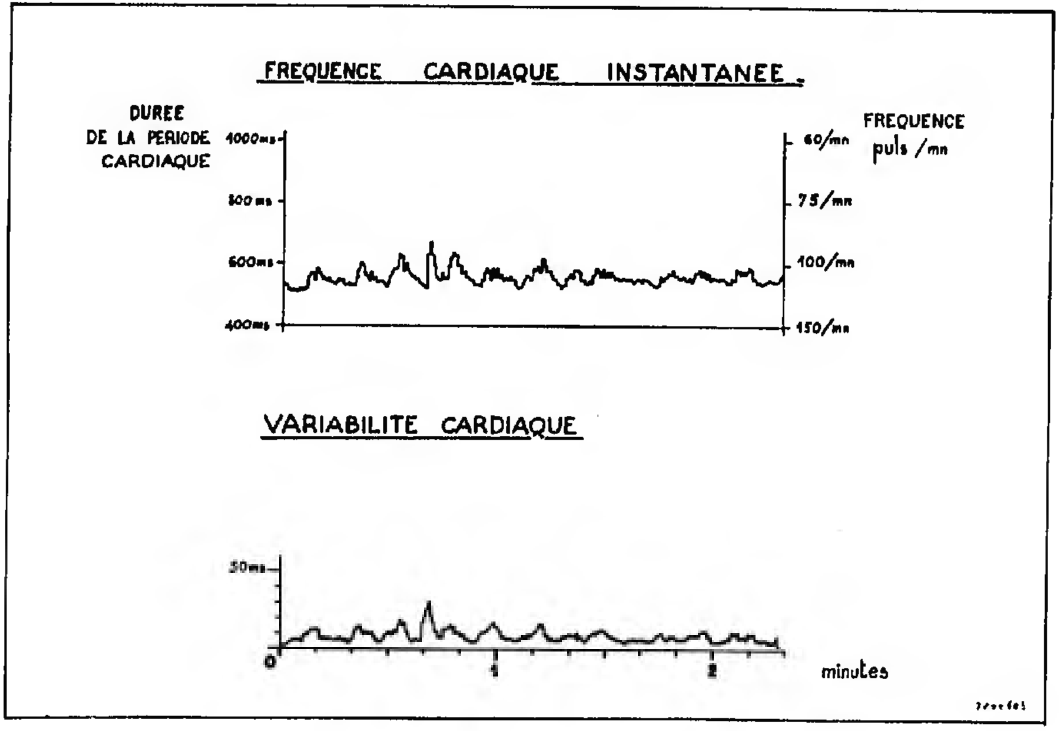

TABLEAU 1

REACTION DE DONAGGIO

- en Vol -

Détail de l'excrétion urinaire par échantillon

Horaire du prélèvement	8^{00} – 9^{00}		12^{00} – 13^{30}		16 – 17^{30}		18^{30} – 20^{00}		21^{30} – 23^{00}	
	quantité par échantil. mg	volume de l'échantil. ml	quantité par échantil. mg	volume de l'échantil. ml	quantité par échantil. mg	volume de l'échant. ml	quantité par échantil. mg	volume de l'échant. ml	quantité par échantil. mg	volume de l'échant. ml
G	7	50	120	250			147	250		
L ....*	4	30	65	150	180	300	230	300	250	300
P	9	40	107	480			120	580		
H	20	40	95	220	93	270				
P	23	440	180	500	40	100				
A	16	140	83	500	208	560				

- Au Sol -

P	9	100	37	340	64	500				
A	31	300	36	300	110	300				
G	17	150	35	290	105	410				
L	15	120	58	310	42	250				

* - Sujet présentant une rhino-pharyngite aigüe. Pendant le vol il consomma aspirine + boissons alcoolisées chaudes.

TABLEAU 2

REACTION DE DONAGGIO

- en Vol -

Totaux de l'excrétion urinaire par sujet

	Total volumes urines ml	Total Donaggio mg	Total Donaggio mg/litre	Durée du vol heure
G	550	272	498	12^{30}
L	1080*	729*	709*	12^{30}*
P	1100	236	214	9^{00}
H	530	208	388	7^{00}
P	1040	243	233	8^{30}
A	1200	307	255	8^{30}

- Au Sol -

P	940	110	117	8^{00}
A	900	177	196	8^{00}
G	850	157	182	8^{00}
L	680	115	169	8^{00}

Pour mémoire :
N = 175 mg /24 heures
Ecart quadratique = 34

* - Sujet présentant une rhinopharyngite aigüe. Pendant le vol il consomma aspirine + boissons alcoolisées chaudes.

TABLEAU 3

17 CETOSTEROIDES URINAIRES

– en Vol –

Détail de l'excrétion urinaire par échantillon

Horaire du prélèvement	8^{00} – 9^{00}		12^{00} – 13^{30}		16^{00} – 17^{30}		18^{30} – 20^{00}		21^{30} – 23^{00}	
	quantité mg	volume ml	quantité mg	volume ml	quantité mg	volume ml	quantité mg	volume ml	quantité mg	volume ml
G	1,3	50	7,0	250			2,4	250		
L		30	2,7	150	3,6	300	5,2	300	3,2	300
P	2,4	440	5,7	500	3,1	100 .				
A	2,8	140	7,2	500	3,1	560				
P	3,9	210			6,1	560				

– au Sol –

P	1	100	4	340	4,9	500				
A	1,9	300	5	300	5,2	300				
G	1,8	150	4,1	290	4,0	410				
L	1,2	120	4,5	310	4,6	250				

TABLEAU 4

17 CETOSTEROIDES URINAIRES

– en Vol –

Totaux de l'excrétion urinaire par sujet

	volume total urines ml	Total 17 cétostéroïdes. mg	Durée de vol heure
G	550	10,7	12^{20}
L*	1 080	14,7	12^{30}
P	1 040	11,2	8^{30}
A	1 200	13,1	8^{30}
P......	770	10,0	7^{00}

* – Sujet présentant une rhino-pharyngite aigüe. Pendant le vol il consomma aspirine + boissons alcoolisées chaudes.

– Au sol –

	volume total urines ml	Total 17 cétostéroïdes. mg	Durée de l'expérience
P	940	9,9	8^{00}
A	900	12,1	8^{00}
G	850	9,9	8^{00}
L	680	10,3	8^{00}

TABLEAU 5

CATECHOLAMINES

- en Vol -

Détail de l'Excrétion urinaire par échantillon

Horaire du prélèvement	8^{00} - 9^{00}		12^{00} - 13^{30}		16 - 17^{30}		18^{30} - 20^{00}		21^{30} - 23^{00}	
	quantité	volume urines ml	quantité	volume urines ml	quantité	volume urines ml	quantité	volume urines ml	quantité	volume urines ml
G	10	50	75	250			115	250		
L *....	9	30	60	150	147	300	140	300	168	300
P		40	130	480			181	580		
P	48	440	210	500	45	100				
A	33	140	195	500	229	560				
P	54	210			160	560				
L	25	70	42	130	125	315				

- Au Sol -

Horaire du prélèvement	8^{00} - 9^{00}		12^{00} - 13^{30}		16^{00} - 17^{30}	
	quantité	volume urines ml	quantité	volume urines ml	quantité	volume urines ml
P	20	100	61	340	30	500
A	33	300	36	300	90	300
G	15	150	42	290	50	410
L	16	120	51	310	29	250

TABLEAU 6

CATECHOLAMINES

- En Vol -

Totaux de l'excrétion urinaire par sujet

	volume total urines ml	total catécholamines	catécholamines /litre	Durée des vols heures
G	550	200	363	12^{30}
L	1 080*	524*	485*	12^{30}
P	1 100	311	282	9^{00}
P	1 040	303	272	7^{00}
A	1 200	457	380	8^{30}
P	770	214	277	7^{00}
L	515	192	372	8^{00}

- Au Sol -

				Durée
P	940	111	118	8^{00}
A	900	159	176	8^{00}
G	850	107	125	8^{00}
L	680	96	141	8^{00}

Pour Mémoire :
N = 354 /24 heures.
Ecart quadratique : 52.

* - Sujet présentant une rhinopharyngite aigüe. Pendant le vol il consomma aspirine + boissons alcoolisées chaudes.

TABLEAU 7

VOL DE 24 HEURES

Réaction de Donaggio et 17 Cétostéroïdes

Détail de l'excrétion urinaire par échantillon

Horaire du Prélèvement	$16^{00} - 17^{30}$			$22^{00} - 23^{00}$			$5^{00} - 6^{00}$			$14 - 15^{00}$		
	Volume urines ml	Donaggio mg	17 cétostéroïdes mg	Volume urines ml	Donaggio mg	17 cétostéroïdes mg	Volume urines ml	Donaggio mg	17 cétostéroïdes mg	Volume urines ml	Donaggio mg	17 cétostéroïdes mg
G	125	19	1,7	230	34	3,2	260	28	5,4	310	164	4,9
P	760	151	6,9	100	6	3,1	615	409	5,2	250	154	2,4
F	235	51	2,3	635	395	5,7	290	201	3,2	285	39	2,1
S	230	41	2,3	120	16	2,6	205	47	5,1	400	190	6,7
G	420	101	3,5	370	148	3,0	270	41	4,2	450	69	4,1

Valeurs moyennes au sol pour 24 heures. Sujets masculins de 20 à 40 ans effectuant au sol un travail normal, suivant les techniques de dosage utilisées au LA.M.A.S.

- Réaction de Donaggio : N = 175 mg/24 heures - écart quadratique = 34
- 17 Cétostéroïdes urinaires : N = 13,5 mg/24 heures - écart quadratique = 2,1

TABLEAU 8

VOL DE 24 HEURES

- Excrétion urinaire Donaggio et 17 cétostéroïdes
- Glycémie avant le vol et pendant le vol (après 20 heures de vol)

	Spécialité	Urines volumes ml/24 h.	Donaggio mg/24 h.	Donaggio mg/litre	17 cétostéroïdes mg/24 h.	Glycémie: mg/litre	
						avant vol	en vol après 20 h. de vol
G	Pilote	925	245	264	15,2	1 050	1 190
P......	Pilote	1 725	720	417	17,6	720	1 160
F	Navigateur	1 445	686	474	14,3	1 050	1 290
S	Navigateur	955	294	307	16,7	780	1 120
G	Radariste	1 510	459	304	14,8	810	1 090

Valeurs moyennes au sol en 24 heures pour des individus de sexe masculin, entre 30 et 45 ans effectuant un travail normal; suivant les techniques de dosage utilisées au LAMAS.

- Donaggio - moyenne	: 175 mg/24 heures	- Ecart quadratique : 34
- 17 cétostéroïdes - moyenne	: 13,5 mg/24 heures	- Ecart quadratique : 2,1
- Catécholamines	: 354 γ /24 heures	- Ecart quadratique : 52
- Glycémie	: 780 mg/litre	- Ecart quadratique : 140

DISCUSSION

PAOLUCCI

Nous savons déjà que la fatigue due au pilotage est un grave problème pour le médecin de l'air, et nous savons aussi que, jusqu'ici, nous ne disposons pas de méthodes biochimiques standardisées pour la révéler; par conséquent, il me semble que vos recherches, ainsi que celles de Mr; Hartman, méritent pleinement d'être prises en considération.

Les questions que je vous pose sont les suivantes:

1. Ne pensez-vous pas que les modifications observées peuvent être la conséquence d'un facteur autre que la fatigue opérationnelle, même d'une forme quelconque de stress, comme par exemple les vibrations et les accélérations?
2. Ne pensez-vous pas qu'il faudrait augmenter le nombre des observations afin d'obtenir des résultats plus statistiquement significatifs?

AUFFRET

1. Il est évident que les vibrations et les accélérations (même de faible amplitude) ressenties au cours des vols de longue durée sont une cause supplémentaire de fatigue;
2. Il serait souhaitable que tous les pays standardisent leurs méthodes d'étude de la fatigue afin d'obtenir un grand nombre de mesures et des résultats statistiquement valables.

EFFECTS OF PART-WHOLE TRAINING PROCEDURES UPON THE ACQUISITION OF COMPLEX SKILLS TO BE PERFORMED UNDER STRESS*

Richard S. Gibson, Ph.D.
Lieutenant, MSC, USN
Chief, Human Factors Engineering Research Division
Naval Aerospace Medical Research Laboratory
Naval Aerospace Medical Institute
Naval Aerospace Medical Center
Pensacola, Florida 32512

Aviation training generally follows a sequential part task approach. However, the solutions to the questions of how many tasks, at what rate, and in what order tend to be more intuitive than empirical. The present study was concerned with the question of how many tasks should be presented at one time.

Seventy-two naval officer candidates participated in the experiment. Each subject experienced one of three training conditions prior to being exposed to the final test condition.

The results provide insight into the use of part-whole training procedures for the acquisition of complex perceptual psychomotor skills. The implications of the results for the selection of training techniques were discussed.

During the course of a normal mission, the military aviator must perform literally hundreds of individual tasks. While all of the tasks contribute to total mission effectiveness, it is possible to separate these tasks into a few relatively independent clusters. For example, the knowledge and skills necessary for flight control are somewhat different from those required for the operation of the weapons systems. Operation of the communication systems and special emergency procedures represent additional task clusters. Since nobody can learn all the necessary skills during a single exposure, aviation training generally follows some type of sequential part task approach. However, the solutions to the question of how many tasks, at what rate, and in what order tend to be more intuitive than empirical. The present study was concerned with the questions of how many tasks should be presented at one time.

Previous studies have indicated human time-sharing capabilities are limited and that the requirement to perform multiple tasks results in a performance decrement. Adams and Creamer (1) found that parallel tasks using separate receptor and effector systems competed for central processing time. The principal result of this competition was manifested in slower response times under multiple task conditions than under single task conditions. Brown, Tickner, and Simmonds (2) in a study of driving while talking over a telephone found that performance on both the driving and communication problems deteriorated. The control skill seemed to be less adversely affected than the perceptual and decision skills. Consequently it would appear that training situations containing multiple competing tasks should be more stressful and less efficient than single task training sessions. Such a result would coincide with the results of a study by Deese and Lazarus (3) which indicated that stress has a greater effect upon psychomotor tasks during the learning phase.

The different qualities of multiple task and single task training sessions should manifest themselves in a subsequent multiple task test session. However, test session performance should reflect both the initial skill proficiency levels and the ability to time share multiple tasks. Fleishman and Parker (4) reported that the most important factor in skill retention was the level of proficiency achieved during initial learning. Consequently the single task training situation should produce better results during the test session than the multiple task training situation. This conclusion must be tempered by the findings of Adams and Hufford (5) that there is a predictable learning-to-time-share factor in the initial performance of time-shared tasks. The learning-to-time-share factor seems to be present only during the first few trials of the time-shared task.

In extending the results of the preceding experiments to the present experiment, the following hypotheses were postulated. (a) Performance during single task training sessions should be better than performance during multiple task training sessions. (b) Single task training sessions should result in better performance during a multiple task test session than multiple task training sessions.

METHOD

Task

Three tasks or groups of tasks were involved in the experiment: a complex coordination task, a complex discrimination task, and a stress task. The complex coordination task consisted of six stimulus lights and control switches roughly corresponding to the detection and correction of aircraft roll, pitch, and yaw. The complex discrimination task consisted of four colored lights (red, yellow, blue, and green) paired with four symbols appearing in four response keys. Every time that the colored stimulus light came on, the S was to press the key containing the correct symbol for that color. For example, if the red stimulus light came on, the S was to depress the key containing the plus symbol. To make the task more difficult, the symbols appeared on different keys on different trials, in addition to which, the colored background of the illuminated symbol varied from trial to trial. For example, on the first trial, the first response key contained a divide symbol with a blue background, on the second trial, a multiplication symbol with a green background, on the third trial, a minus symbol with a red background, etc. The stress task consisted of a red stimulus light and response switch associated with the warning and avoidance of impending shock, and a yellow stimulus light and response switch associated with the indication and avoidance of an impending system malfunction. If the S made an appropriate response within 4 seconds, the shock or control malfunction could be avoided.

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*Opinions or conclusions contained in this report are those of the author and do not necessarily reflect the views or endorsement of the Navy Department.

Subjects

Seventy-two Ss participated in the experiment. They were all male naval officer candidates undergoing training at the U. S. Naval Air Station, Pensacola, Florida. Problems associated with the computer system running the experiment resulted in the loss of data for three of the original 72 Ss. The final S population consisted of three groups of 23 Ss.

Apparatus

The experiment was fully automated. All stimulus sequences and all responses were presented, monitored, and time-tagged by means of a UNIVAC 418II computer. All stimulus and response elements were mounted in test enclosures that form a part of the Multipurpose Automated Research Test System (MARTS). (MARTS is part of an automated test system being developed at the Naval Aerospace Medical Research Laboratory.) The stimulus elements were mounted behind one-way glass panels that allowed the stimulus element to be seen only when illuminated. The response keys, except for two floor mounted foot controls, were mounted on a desk type of control console.

Procedure

Each group of Ss experienced one type of training session followed by a test session. Group I had two single task training sessions. The first training session consisted of 108 trials, one trial every 2 seconds, of the complex-coordination task. The second training session consisted of performing the complex-discrimination task for 216 seconds. The total time for the two training sessions was 432 seconds. Group II had a single 432 second training session. The 108 trials of the complex-coordination task were presented at the rate of one trial every 4 seconds. The complex discrimination task was available throughout the training session. Group III had a 432 second training session which was the same as that for Group II except that the stress stimuli were presented 12 times during the session. Six red and six yellow stimulus lights were presented. The response switches would turn off the stress lights, but the S was not penalized in anyway for not making the appropriate responses.

After the training session(s) the Ss had the test session consisting of all three tasks: complex-coordination, complex discrimination, and stress. Three different time intervals were used for pacing the complex-coordination task: 8 second intervals for the first 36 events, 6 second intervals for the second 36 events, and 4 second intervals for the final 36 events. The stress tasks appeared 12 times: 6 warnings of impending shock and 6 indications of impending systems malfunctions. Performance on all tasks was scored in terms of response latencies. Response times are accurate to the nearest hundredth of a second.

RESULTS

Performance during the training sessions was difficult to evaluate because of the erratic behavior of many of the Ss in Groups II and III. Since many of these Ss practiced one task to the partial or total exclusion of the other it was impossible to assess the group performance in terms of response times. As an alternative the number of correct responses during the learning session was evaluated. The character of the task performance by the different groups is illustrated in Figures 1 and 2. The number of S's making perfect scores of 108 correct coordination responses is significantly different for Group I than it is for Group II and Group III. The comparison of Group I with Group II yielded a chi-square value of 5.76 with 1 df, $p<.05$. The comparison of Group I with Group III yielded a chi-square value of 5.00 with 1 df, $p<.05$. The differences between Group II and Group III were not significant. Performance on the complex discrimination task was more variable for Groups II and Group III than for Group I. A chi-square test comparing the number of extreme scores in the three groups was significant, 6.13 with 2 df, $p<.05$.

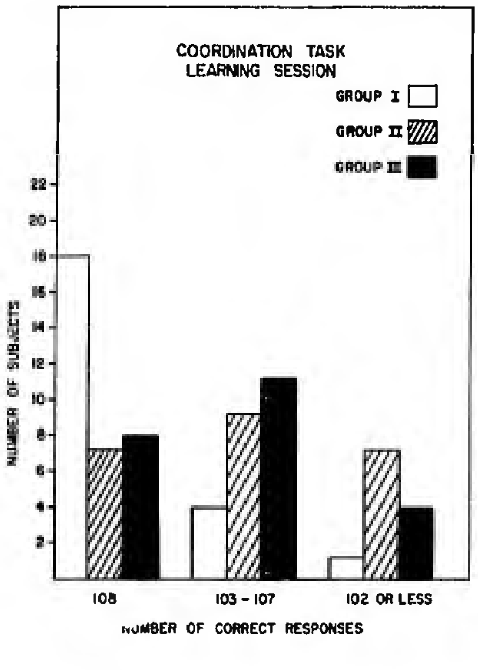

Figure 1

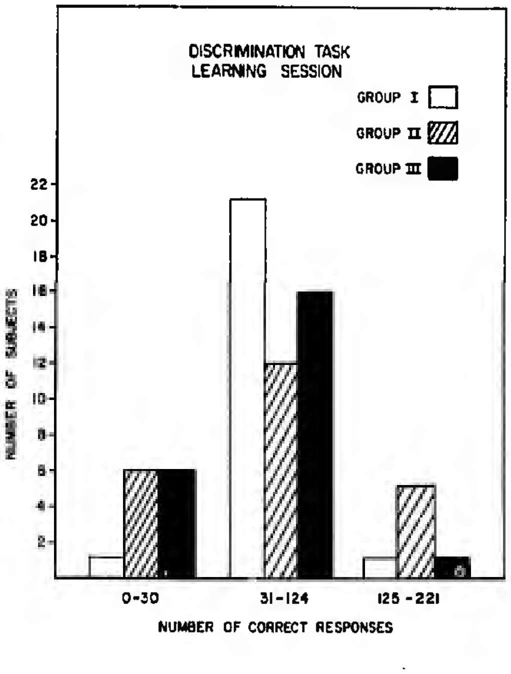

Figure 2

Evaluation of the test session performance of the three training groups presented other problems. Very large differences in within-group variability were present. Since these differences in variability differed independently of differences among the means the use of standard parametric statistical analyses on either the raw or transformed latency scores was abandoned (6) in favor of a series of non-parametric statistical techniques (7, 8). Since performance on all of the tasks was measured in terms of response latency, it seemed reasonable to ask whether the tasks were measuring different skills or only a common speed factor. The results of running Spearman rank correlations on the task performance of the three experimental groups is presented in Table I. Groups I and III show a significant correlation between performance on the coordination task and performance on the stress task. Group II shows a significant correlation between the discrimination task and the coordination task. None of the groups show a significant correlation between the discrimination task and the stress task. Since the correlations between the correlations the discrimination task and the coordination task vary greatly among the three groups and since only one of the correlations can be considered statistically significant, there is probably very little intrinsic correlation between the two tasks. Since the correlations between the coordination and stress tasks are all of a similar magnitude and since two of them are statistically significant, there probably is a significant intrinsic correlation between the two tasks.

Table I

Spearman Rank Correlations Between Tasks

Group	Discrimination vs Coordination	Discrimination vs Stress	Coordination vs Stress
I	.08	.12	.45*
II	.50*	.26	.35
III	.28	.07	.41*

Test session performance on the coordination and discrimination tasks is presented in Figure 3. The discrimination task is clearly more time consuming than the coordination task. Except for the coordination response times during the first trial block, the performance for Group I is as good or better than the performance of the other two groups. Group I is the only group to display consistent improvement on the discrimination task during the first four trial blocks while simultaneously improving performance on the coordination task.

Part of the difficulty in analyzing the data seems to be the result of a training by ability interaction which had not been anticipated in the original experimental design. Kolmogorov-Smirnov comparisons of the score distributions of the upper and lower twenty-five per cent of the test groups provide some insights to this interaction effect. Detailed analysis of performance on the discrimination task indicated that there were no significant differences among the upper twenty-five per cent of the three experimental groups. However, the same type of analysis indicated that among the lower twenty-five per cent of each group there were significant differences. The poor performers in Groups II and III were significantly worse than were the poor performers in Group I, $K_D = 17$ & 13, $p<.05$. Detailed analysis of performance on the coordination task indicate that there were no significant differences among the lower twenty-five per cent of the three experimental groups. However, the same type of analysis indicated that among the upper twenty-five per cent of each group there were significant differences. The best performers in Group II were significantly better than the best performers in Group I, $K_D = 17$, $p<.05$.

DISCUSSION

The results generally favor the interpretation that single task training sessions provide better results than an equal amount of time spent in multiple task training sessions. The results from the training sessions indicate that sequential acquisition of single tasks provides a higher base level of performance and a more homogeneous quality of skill acquisition. In contrast the exposure to multiple tasks during the training session results in less uniformity and greater variability in the quality of skill acquisition.

The hypothesis that the single task training sessions would result in better performance during the test session was confirmed. Group I did display a learning to time share effect during the first trial block of the test session. After this first trial block, the coordination task performance continued at a rate that was at least equal to the other groups. It is important to note that Group I was also improving on the discrimination task during the first four trial blocks, while the other groups were not making any significant improvement. Consequently, when the joint performance on multiple tasks is considered, the level of proficiency attained on the separate tasks during the training period appears to be more important to later performance than early exposure to the multiple task situation.

All groups displayed a decline in the quality of their performance on the discrimination task during the fifth trial block. Apparently intrusive stimulus events such as those in the coordination and stress tasks are given a higher priority than the sustaining stimulus events which depend on individual volition.

The ability by training experience interaction has considerable implication for training methodologies. Early exposure to multiple tasks under conditions in which the S has some choice in how his time is allocated produces a wide spread between individual performance quality. As noted in the experimental results, the good performers become very good and the poor performers perform very poorly. Since it is the less adept who present the greatest training problems and since some measure of quality control is one of the objectives of most training programs, the results indicate that a sequential series of single task training sessions would provide the best results. Questions concerning the order and rate of introducing new tasks will be addressed in future experiments.

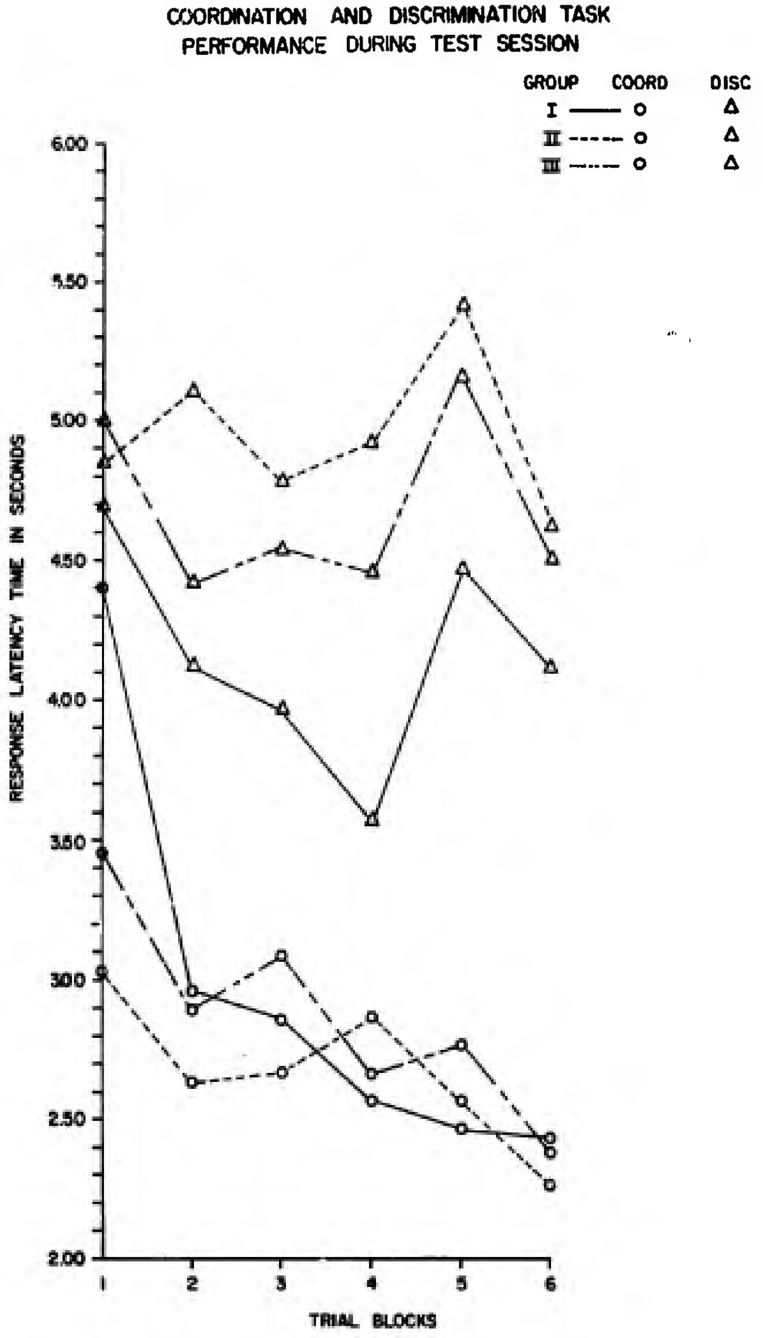

Figure 3

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PERFORMANCE MEASUREMENT USING PILOT CONTROLLED Gz MANEUVERING WITH A SIMULATED OPERATIONAL TASK

Captain D. B. Rogers, Dr. F. M. Holden, Dr. C. R. Replogle, Dr. G. Potor,
Major C. N. Day, Mr. R. E. Van Patten, Captain K. A. Smiles and Colonel G. C. Mohr

Aerospace Medical Research Laboratory
Wright-Patterson Air Force Base, Ohio 45433

SUMMARY

A technique for human performance measurement using a closed loop centrifuge has been validated. The study was performed on the Dynamic Environment Simulator (DES) operating in a closed loop mode. The simulation utilized the pitch and roll dynamics of a high performance aircraft. The measurement criteria was hits on target using a display generated heads up gunsight on a maneuvering target aircraft. An important consideration was relationship between man as a passive rider versus man as an active participant in the generation of the Gz stress. Two important demonstrations resulting from this study are: (1) there is a significant difference in the ability of subject pilots to perform in closed versus open loop configuration and (2) it is feasible to provide a mission related human performance metric in a selective simulation in which the +Gz forces are dynamically realistic. A predictive heads up gunsight display is utilized with target trajectories representative of aerial combat maneuvers; and on line performance measures and immediate performance feedback are provided.

INTRODUCTION

In air to air combat, the pilot seeks to obtain a tactical advantage over his enemy by exploiting both his own capabilities and his aircraft's performance and armament through optimal combat maneuvering and tactics. In practice, such maneuvering is opportunistic, employing an adaptive sequence of offensive and defensive actions. Representative combat scenarios require execution of one or more basic combat maneuvers. Several of these, for example, the hard turn, the high G barrel roll, and the scissors, involve a minimum radius turn exposing the aircrewman to maximum acceleration stress over considerable durations of time. Since the crewman may receive several exposures during the aerial combat encounter, it is necessary to quantify not only the immediate effect of G but also the cumulative effect of repeated acceleration exposure on aircrew performance and physiology. In addition, it is important to note that aircraft ordnance is not fired at the peak or high G portion of the encounter but rather at lower (2-4 G) plateaus between or following high G peak. Such profiles have been called G on G.

There are significant difficulties in assessing the capabilities of a pilot to perform a given mission with a given weapons system using classical acceleration tolerance data. Physiologic information gained from Gz tolerance research is generally limited to cardiovascular data. The performance data available uses classic methodology, tracking on unknown plants, and minimally defined forcing functions. Further, there is no relationship between the specific task goals tested and the weapon systems mission goals.

While cardiovascular studies have provided insight to basic mechanisms responsible for psychophysiological decrements in +Gz, extrapolation to performance in an operational sense is difficult. This experiment is the first of a series designed to answer specific questions of performance of man in weapon systems. The elements of the experimental design which have been established will be constrained to meet operational needs of the stress (acceleration profile), the task, the crew station, the measure or metric, and the analysis.

A suitable approach to this problem must satisfy certain criteria: (1) the objectives must be specifically defined, (2) critical mission factors must be realistically simulated, (3) pertinent measures of mission performance must be obtained, and (4) suitable analysis procedures must be available. It is particularly important to provide pertinent measures, that is, measures that are both objective and sensitive to changes in the mission variables. Ideally, interpretation of the results obtained should allow prediction of mission success or degradation as a function of imposed acceleration stress on the pilot. The method of choice is the system effectiveness technique. Critical phases of the aerial combat mission are simulated with the pilot-in-the-loop, and the effect of G determined by target and chase plane performance envelopes, is measured in terms of an air to air weapon delivery miss distance distribution. The data provides direct insight into how well a pilot can achieve target lock-on and how accurately he can deliver ordnance in the face of serial exposures to the G environments that are commanded by his own flight control inputs during the simulated combat engagement.

The specific objectives of this study are as follows: (1) to measure, under closed loop motion conditions, the effect of high intensity acceleration on the pilot's ability to make precise flight control adjustments while seeking successful target lock-on and deliver air to air ordnance accurately against the evasive enemy target, (2) to measure in the same terms the cumulative effects on pilot performance of serial application of these severe load factor conditions and (3) to measure in the same terms the effects on pilot performance of air to air maneuvering prior to peak +Gz loading and weapons delivery. The measures selected are intended to provide a predictive index of man-vehicle-weapon system effectiveness in severe acceleration environments, defining pilot capability to exploit the performance envelop of advanced air superiority fighters.

SUBJECT SELECTION

The subject panel consisted of qualified members of the Aerospace Medical Research Laboratory Acceleration Hazard Duty Panel. Air Force Technical Order restraint and support was provided by a Martin Baker ejection seat mounted in the gondola of the Dynamic Environment Simulator (DES). The seat was mounted in a physically standard HIAD cockpit. All subjects had previously been indoctrinated on the closed loop operation of the DES with special emphasis placed on blackout avoidance. All subjects were monitored with sternal lead EKG, closed circuit television, and hot mike communication.

HEADS UP GUNSIGHT

The gunsight provided the primary visual cues for the air to air tracking task. The sight and target were computer generated and electronically displayed to the subject with appropriate scaling for dynamic fidelity. The sight was located in the standard position for the F-4 series aircraft. The gunsight display also provided a simulation of lead angle computation as is necessary for accurate performance measurement. Certain assumptions were made to simplify the simulation and the analysis. The assumptions were that the corrective angles in aligning the sight are small and that they are a function of G forces, range, and velocity of the round. The sight display is depicted in Figure 1.

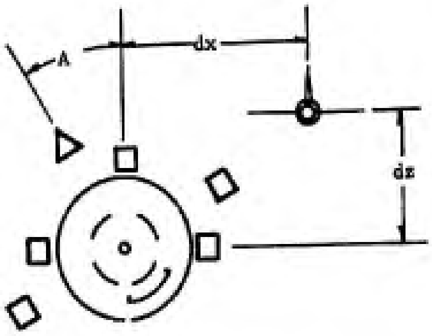

FIGURE 1. Heads up sight display. A is roll angle, dx represents yaw displacement and dz represents pitch displacement from target alignment. Both dx and dz include prediction offsets. Chase plane is in right roll.

ENCOUNTER PROFILES

The subjects were required to align the gunsight which responded to the instrumented output of control stick movements. The control stick signal was processed through an analog set of simulated airframe dynamics for a high performance aircraft. The target had a random appearing forcing function in the roll axis and a haversine function on the pitch axis. Three different control configurations were used on the DES: (1) the gondola or cabin was stationary throughout the task (G_1); (2) the DES was rotating to impose a constant 1.5 Gz load on the subject (G_2); (3) the DES was closed loop in the physiologic pitch axis and responded in +Gz loading according to pitch deflections of the control stick (G_c). The system diagram is shown in Figure 2.

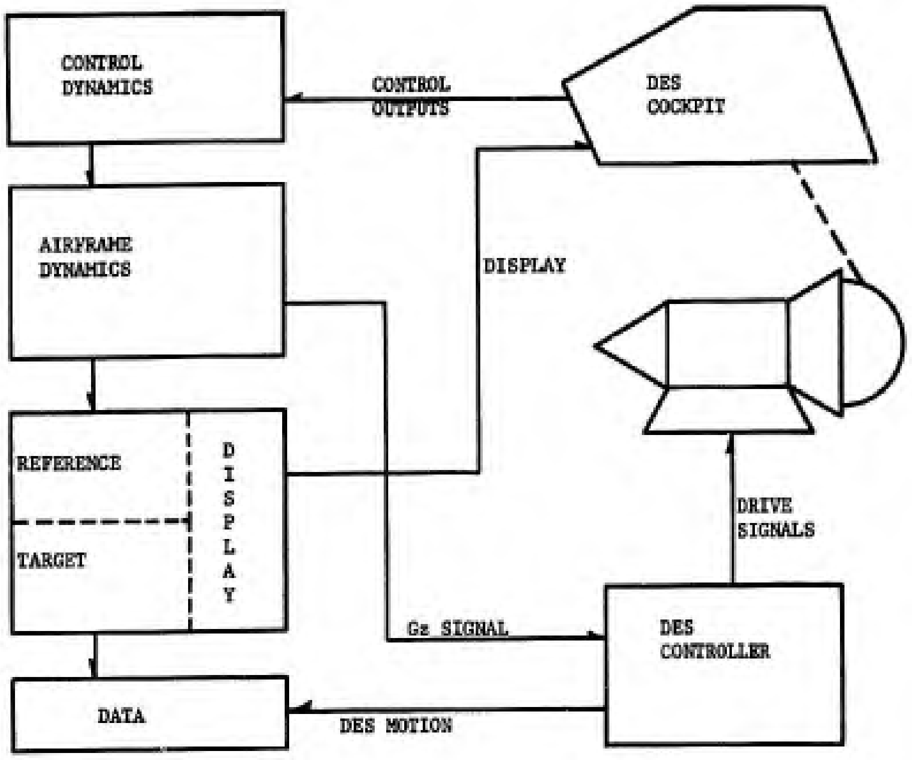

FIGURE 2. DES closed loop air to air control scheme.

The subjects were required to fly a standard noncombatant course at a specified altitude and heading. The target vehicle and gunsight were presented on his display, and he was required to achieve a 6 o'clock position behind the target and track it with the heads up lead angle gunsight. A typical pitch axis encountered is shown in Figure 3.

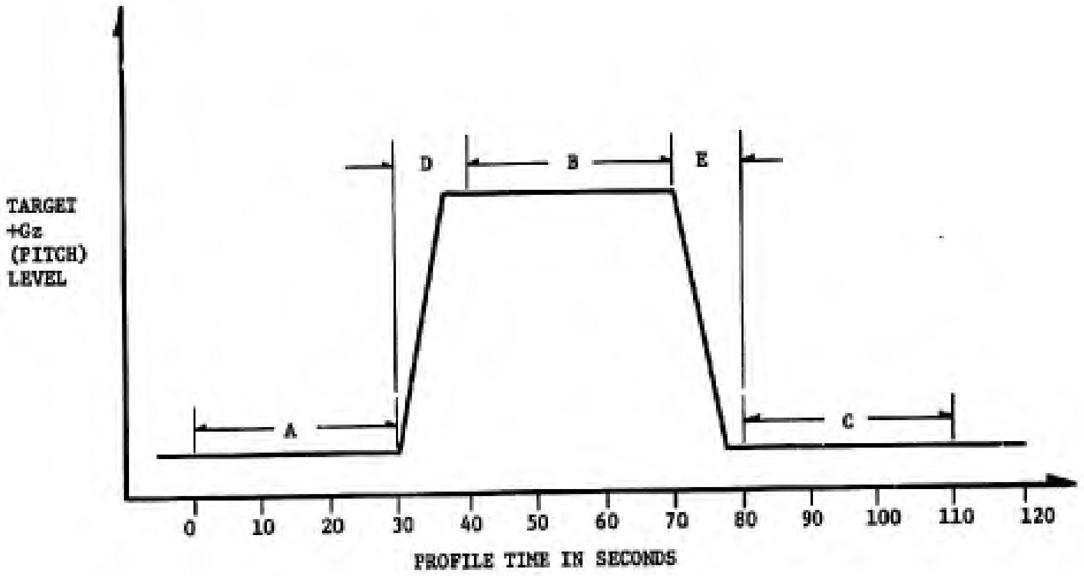

FIGURE 3. Typical target chase profile for all runs.
A, B, C are scoring periods (pre, during and post),
D and E are transient periods with no scoring.

Again certain assumptions were made for ease of simulation: (1) the target is an idealized aircraft traveling at the same air speed as the subject's aircraft; (2) all turns are coordinated and at constant altitude. The aircraft pitch G load was calculated by analog computer and transformed to subject Gz load by changing the rotational speed of the DES. For this experiment, the peak Gz used during the G_c runs was set at 4 G. Target roll axis maneuvering was generated by a set of six non-harmonically related sine waves of equal amplitude. Roll axis control by the subject affected only the gunsight display and was not translated into physiologic roll axis movement. The subjects tracked about 25 minutes per day for 12 days. Each day was broken up into 3 time epochs and each epoch consisted of a randomized set of the three control configurations, G_1, G_2, and G_c. Thus, the subject had 9 profiles a day or 3 of each type per day.

The subject was given an increment in scoring when both pitch and azimuth deflections of the sight were within a preset criteria. Scoring for the task was done on line. The scoring periods used in this experiment correspond to parts A, B, and C of Figure 3. No scoring was done during the transient periods. At the end of each profile, the subject was provided with his scores. At the end of each subject's day, paper tape was automatically generated with scoring information and other variables of interest.

MEASUREMENT AND ANALYSIS

An analysis of tracking error as a metric for tracking performance of weapon systems has elucidated a major fault. In weapon systems, a predictive firing system is normally used. With these systems, post tracking information (normally second order prediction) is used to aim the weapon so that the manner in which that target is tracked as well as the average error is imparted to pointing accuracy. If only tracking error is used for performance and where the weapon is pointed is neglected, totally erroneous results can occur. Therefore, in these studies, the predicted "hits on target" or kill probability is used as a metric.

Previous analyses of tracking error with disturbed high performance aircraft dynamics have shown Gaussian probability distributions. Analysis of variance, therefore, will provide the means for confidence estimates on degradation after acceleration peaks. The analysis provides information on how tracking changes during the experiment and how tracking changes during and after "tolerable" acceleration levels. The question of whether a pilot can effectively operate his weapons after performing the high G peak maneuver required to pitch up to encounter a target aircraft in an evasive turn can be directly analyzed. Additionally, time to firing, RMS error before tracking, RMS error after firing, population tolerance, training effects, subjective responses of subjects, tracking during G peak, and time to return for tracking after peak can be analyzed.

RESULTS AND DISCUSSION

The calculated hit scores are found in Table 1 and portray the overall results of the first experiment run with the system.

TABLE 1

	Hits		
	1 G	2 G	Closed Loop (G_c)
Pre G	41.7	40.3	34.3
During G	31.4	32.5	27.9
Post G	37.9	36.5	29.9

The tabular form shows that only a very insignificant difference can be noted between the static scores and the idling scores (1 G, 2 G); however, with equal tasks, the closed loop score (G_c) shows a marked decrement in the pre G condition. There is a noted decrement in all columns in the hard turn maneuver for all levels. The only G stress was imposed in the closed loop control configuration. The post turn scores indicate a drop off from the pre turn scores with the most marked drop off being apparent in the closed loop post G score.

The subject variation was the greatest in the analysis as shown in Table 2.

TABLE 2

	Mean	
Subject 1	38.9	
Subject 2	38.0	$p<.005$
Subject 3	27.3	

The day interaction shows a training curve which is only beginning to flatten at 12 days.

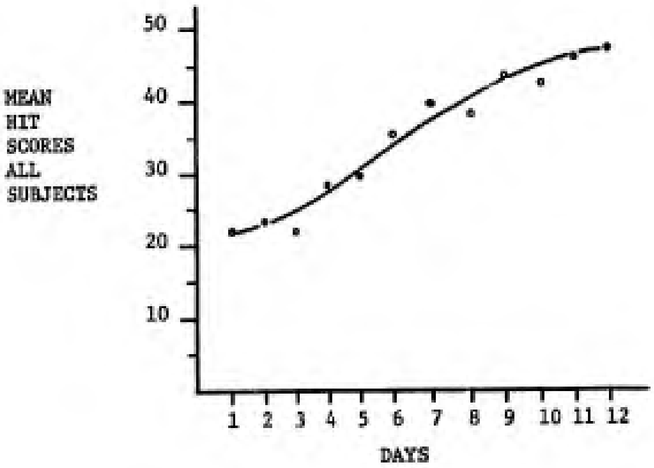

FIGURE 4. Training curve averaged across all subjects.

The hit scores averaged for control configuration demonstrates the very significant difference in closed loop versus open loop operation.

TABLE 3

G_1	37.0	
G_2	36.5	$p<.005$
G_c	30.7	

CONCLUSIONS

The significant differences in the open versus the closed loop control configuration may indicate that the closed loop task on the centrifuge in itself imposed a stress on the subject pilot leading to decreased performance in this configuration. This also indicates that the closed loop task study method is necessary for more accurate prediction in the operational situation.

The decay in performance shown at the nominal level of 4 G is plausible and indicates that the man-machine system has a decreased efficiency under relatively low stress levels. More important, however, is the after G effect that is seen in the post 4 G maneuvering. The primary task of gun firing is done after the G stress period and decay in performance at this time is operationally highly significant.

The subject training curve indicates that long training periods are required for this type of task. The curve suggests that some training period longer than the 30 minutes per day, 12 day period would be more ideal for this type experiment. Subject availability is, however, a limiting factor.

The most significant result of the experiment, however, has been a demonstration that useful selective simulations of operational environments can be realized and mission related metrics can be used to predict performance in operational environments. The essential dynamics of the controlled vehicle can be simulated and used to provide a dynamically realistic closed loop G environment. Further, on line processing of tracking data and immediate feedback can be provided, and rapid analysis and experimental turn around time can be accomplished.

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Further reproduction is authorized to satisfy needs of the U.S. Government. The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 80-33. The research reported in this paper was conducted by personnel of the Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. This paper has been identified by Aerospace Medical Research Laboratory as AMRL-TR-72-3.

"Physiological Studies of Fatigue in Activities Requiring Mental Concentration in Hot Climate, the Influence of Positioning and Sensorial Irritation".

by

J. Meyer-Delius
Major, MD
Institute of Aviation Medicine of the German Air Force
808 Fürstenfeldbruck Air Base

SUMMARY

Activities of vigilance without additional influence of psychical stress or energetic upset is demonstrated in hot and temperate climate with noradrenergetic reaction. Mental effort with slightly increased energetic metabolism required 20 % more time in hot climate, $25{,}1\,^{\circ}C_{eff.}$, to complete tasks than was required by persons working under temperate conditions. In this case the pulse rate was rising continuously. Under identical conditions of climate and mental work, but with noise, the pulse rate was significantly higher than without sensory irritation. Excitation of the sensorial senses leads to an additional increase in the peripheral vascular constriction. Opposed to thermoregulation it can cause disregulation and thus fatigue.

The technical development of working places poses problems to physiology relating to stress during activities requiring vigilance and in particular to tasks of monitoring and control. In this context simultaneous demands on parts of the blood circulation cause additional interest due to the regulation of body temperature. Through statistical studies HACKWORTH (1), VITELES and SMITH (2) found an exponential increase of the number of errors when the effective temperature is rising above $26\,^{\circ}C_{eff.}$ during number checking tests, mental multiplication tests, coding tests, wireless telegraphy reception tests, lathe tests and heavy pursuimeter tests. OSBORNE, VERNON and MUSCIO (3) reported that accidents among laborers in munition factories have increased about 40 % during an air temperature of 25°C as compared to the accident frequency during 20°C ambient temperature. In the following we attempt to contribute to the clarification of the loss of vigilance capacity in hot climate.

Figure 1 shows the relationship between skin and air temperature. At a temperature of 23°C the skin temperature of the finger tip was 29,2°C and during an ambient temperature of 29,7°C the skin temperature was found to be 31,2°C. There is only a temperature difference of 1,5°C which is insufficient to emit heat basal metabolism by means of heat convection to the outside. Blood circulation in the arm has been interrupted in the dashed area. It is evident that skin circulation in hot climate exerts only a small influence on the skin temperature. The limitation of heat emission through convection leads to cutaneous vasodilatation Figure 2, and to sudation. According to WYNDHAM (4, 5) the significant increase takes place at 33°C skin temperature.

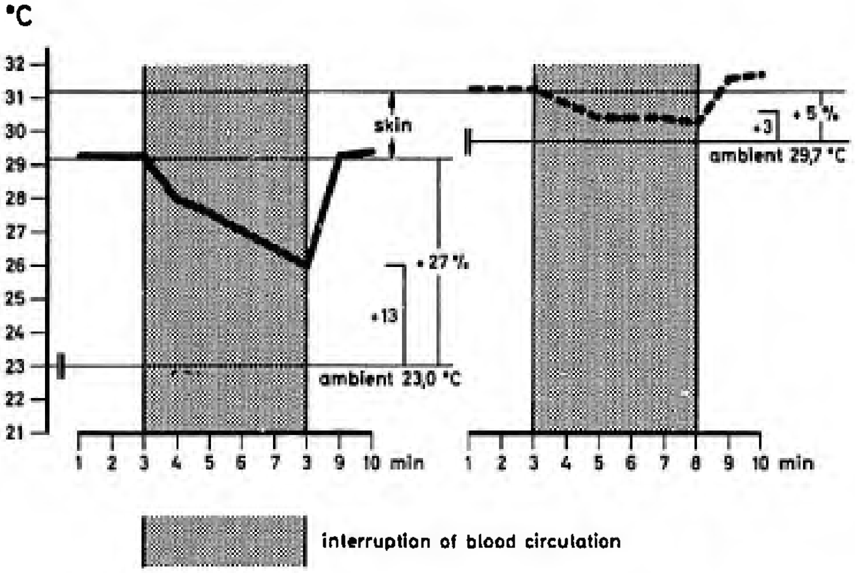

Figure 1, skin temperature at the finger tip in relation to ambient temperature during free and, dashed area, interrupted blood circulation in the arm.

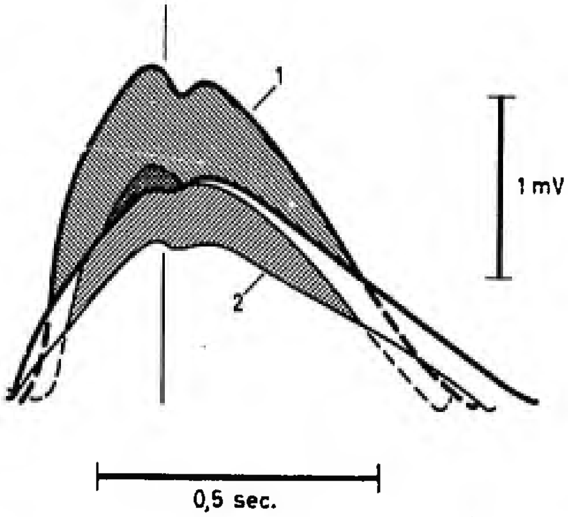

Figure 2, light plethismography of the volume pulse at the lobe of the ear (mean value of 20 pulses).
Pulse waves 1: sitting
Pulse waves 2: standing,
upper limitation of the dashed areas: at $26,3^{\circ}C_{eff.}$
lower limitation at $19,6^{\circ}C_{eff.}$

Figure 2 shows the volume waves of the pulse registered at the lobes of the ear while sitting and standing. They were recorded with light plethysmography and registered as mean values of 20 pulses each. It is interesting to note that the difference in effective temperature will change the peripheral vasotonus relative to it conditioned on the various forms of posture. In an average of 10 subjects the blood pressure while sitting will decrease from 124/76 to 108/72 mm Hg simultaneously with a temperature rise from $19,6^{\circ}C_{eff.}$ to $26,3^{\circ}C_{eff.}$, and while standing from 126/90 to 110/80 mm Hg. The heart rate will rise with the effective temperature from 64 to 77 while sitting and from 71 to 83 pulse rate/min while standing.

We can observe a similar relation between two factors acting on the peripheral resistance of the circulation in the case of constrictor tonus during vigilance and vasodilatation for heat emission. During the first observations we tried to prevent a measurable increase of energy metabolism in order to assess only the influence of vigilance. The subjects were trained, they pressed three buttons with three fingers and thereby responded to 11 signals, combinations of green, red and white lights and high and low acoustic signals. During a 30-minute period 600 signals had to be answered correctly, each one in less than one second. The error amounted to 4 ± 0,7 % under both climatic conditions. The energy metabolism between rest and activity revealed no measurable difference. In Figure 3 all measurements have been related to the time before starting to work in moderate climate, namely $17,6^{\circ}C_{eff.}$ The upper portion of the diagram shows relative changes caused by vigilance in a temperate climate. The amplitude of the volume pulse and the pulse rate decrease in the sense of a noradrenergetic reaction. The respiratory rate increases 70 %. The lower left portion of the figure presents the increase of the volume pulse amplitude and the pulse rate in hot climate during a rest period and in the lower right section we illustrate the same influence brought about by noradrenergetic changes in the hot climate, as we have seen under vigilance in moderate climate. This change takes place in relation to the initial value during the time of rest.

When the circulatory regulation during vigilance is connected with a simultaneously slight increase of energy metabolism, the vegetative system changes from a noradrenergetic to an adrenergetic picture, with an increase of the heart rate. The peripheral vasoconstriction caused by vigilance remains, in spite of simultaneous requirements for heat emission. 10 young male subjects were required to perform an eye-hand coordination task and measure 240 lines having a length of 3 - 24 mm in a particle analyzer. In doing so the energy metabolism rises from 2,2 kcal/min during the time of rest to 3,0 kcal/min during the time of activity.

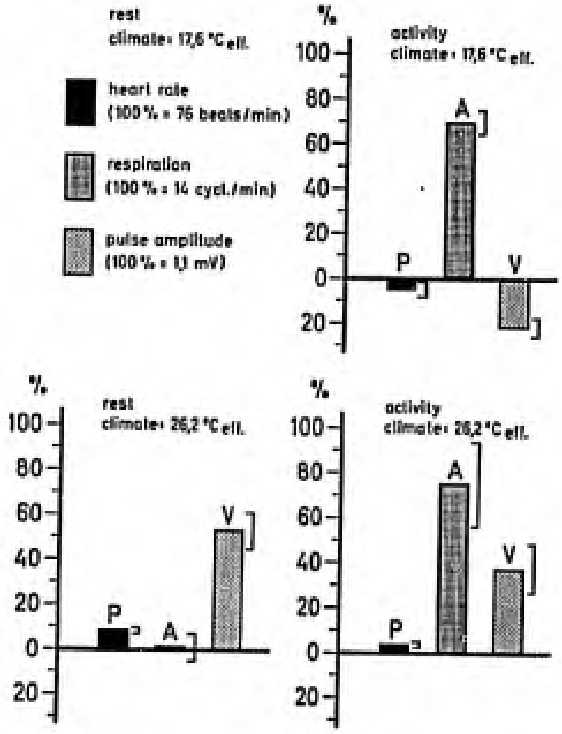

Figure 3, pulse rate, respiratory rate and amplitude of peripheral volume pulse at rest (left side of the diagram) and during vigilance (right side) in temperate climate (upper portion) and in hot climate (lower portion). Relationship to values at rest in temperate climate. (13 subjects).

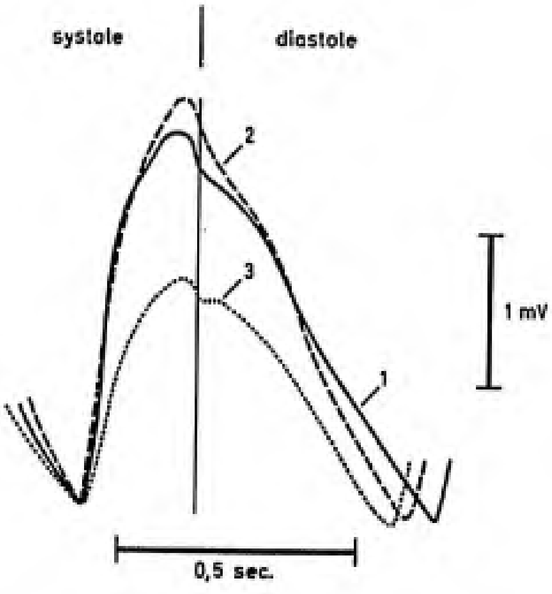

Figure 4, light plethysmography of peripheral volume pulse, registered on ear lobe in climates with 26,4°$C_{eff.}$ (mean values of (20 pulses).

Curve 1: at rest, energy metabolism 2,2 kcal/min

Curve 2: at rest, energy metabolism 3,0 kcal/min

Curve 3: activity requiring vigilance, energy metabolism 3,0 kcal/min.

In figure 4, curve 1 illustrates the volume pulse at rest, curve 2 shows a slightly raised amplitude of the volume pulse and a higher pulse rate. This curve was traced during the performance of the required measuring motions without the subjects being required to be vigilant. Curve 3 corresponds to the volume pulse while performing measurements unter vigilance. Vigilance is linked to vasoconstriction even though the same activity without vigilance, curve 2, induced an enlargement of the amplitude of the volume pulse. If one observes the pulse rate during the performance of the stated task for a prolonged period of time, Figure 5, it becomes evident that in the cooler climate at $14,3^{\circ}C_{eff}$, curve CL,1 the pulse rate increases with the start of the vigilance activity, maintaining the same level during the time of activity, whereas in a hot climate, at $25,1^{\circ}C_{eff}$, the pulse rate increases continuously during the work period and thus shows a disregulation, curve A,1. Noise of 85 dB (B) will displace the curves to higher pulse rates, curves CL,2 and A,2. Thereby the pulse difference remains because of the climatic difference.

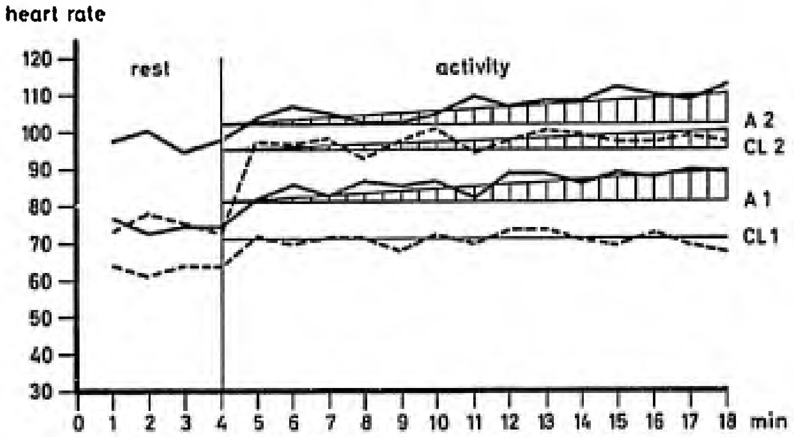

Figure 5, pulse rate during energetically light work (3,0 kcal/min)
requiring vigilance,
A-curves: during ambient climate of $25,1^{\circ}C_{eff}$.
CL-curves: in a climatized room, $14,3^{\circ}C_{eff}$.
Curves 1: without noise
Curves 2: with noise of 85 dB (B)
(10 subjects)

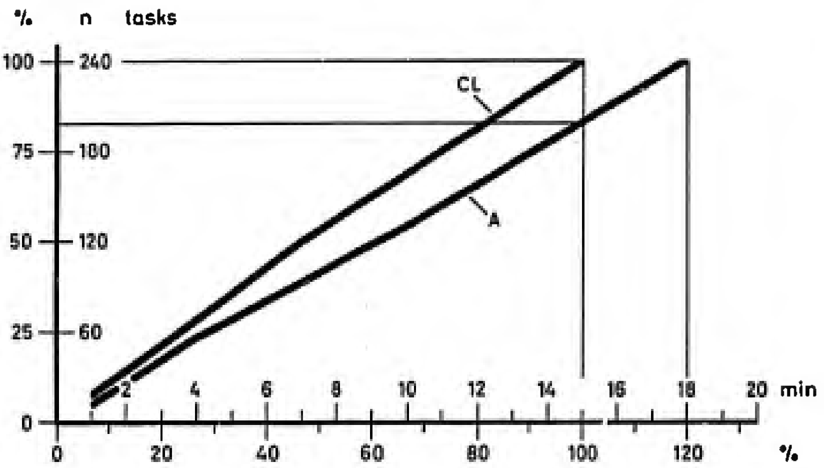

Figure 6, climatic influence on work duration while measuring 240 lines of 3 - 24 mm length,
A-Curve, during ambient climate of 25,1 $^{\circ}C_{eff.}$
CL-Curve: in a climatized room, 14,3 $^{\circ}C_{eff.}$ (10 subjects)

As shown in Figure 6, the test persons required 20 % more time for the performance of the above task in hot climate than in moderate climate. With 3,5 and 3,6 % in both test series the error number did not show a significant difference. A longer familiarization with the measurement technique preceded.

It was found that sensorial noise stimulation exerts an influence on the peripheral circulation even though it is already influenced by thermoregulation, orthostatic adaptation and the regulation of vigilance. Thereby the interaction of the regulatory tasks of the circulation will cause an increase or decrease of the heart rate. In Figure 7 we measured pulse rate and, in a plethysmographic way, the amplitude of the peripheral volume pulse at times with and without noise with 90 dB (B) and 250-2000 Hz. In a cooler climate with 20,6 $^{\circ}C_{eff.}$, curve B, as in a hot climate of 26,3 $^{\circ}C_{eff.}$, curve A, noise caused a decrease in the volume pulse amplitude, also during a circulatory periphery, which is dilated for heat emission. Simultaneously there was a small decrease in pulse rate. Figure 8, representing the measurements in hot climate, shows an increase of the pulse rate during noise under the same degrees of effective temperature and same noise intensity and frequency as in figure 7 in one and the same subject. In the last case a change of body posture from sitting to standing had decreased the volume pulse amplitude and increased the pulse rate already before the noise set in.

Figure 9 shows the increase of the cutaneous blood circulation measured in ten young male subjects according to the Hensel method (6). On one hand the increase in blood volume/min was caused by a slight elevation of the effective temperature and on the other hand by a change of position, sitting on a chair and on a stool. On the chair an increase of the climate from 22,9 °C, 62 % R.H. to 30,1 °C, 73 % R.H. caused the energy metabolism to increase slightly from 2,1 kcal/min to 2,4 kcal/min on a stool from 2,5 kcal/min to 2,8 kcal/min.

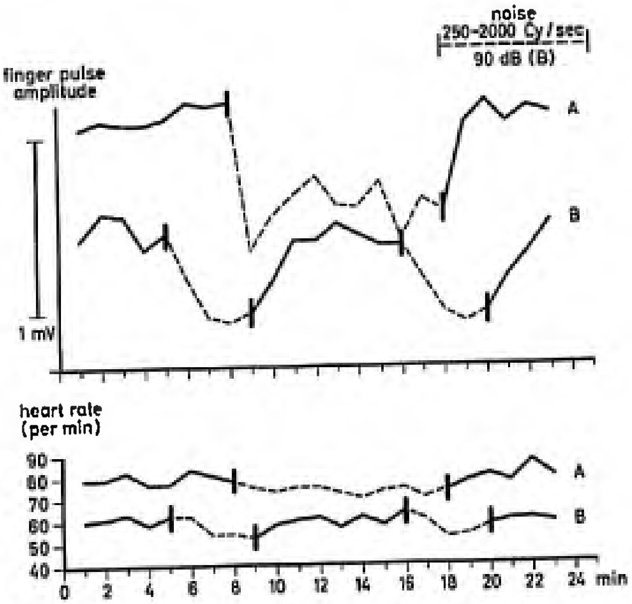

Figure 7, plethymography of amplitude of finger volume pulse during 26,3°C$_{eff}$, curve A and 20,6°C$_{eff}$, curve B, dashed lines = time with noise: 90 dB (B), 250 - 2000 Hz
(GOETHE, MEYER-DELIUS (7))

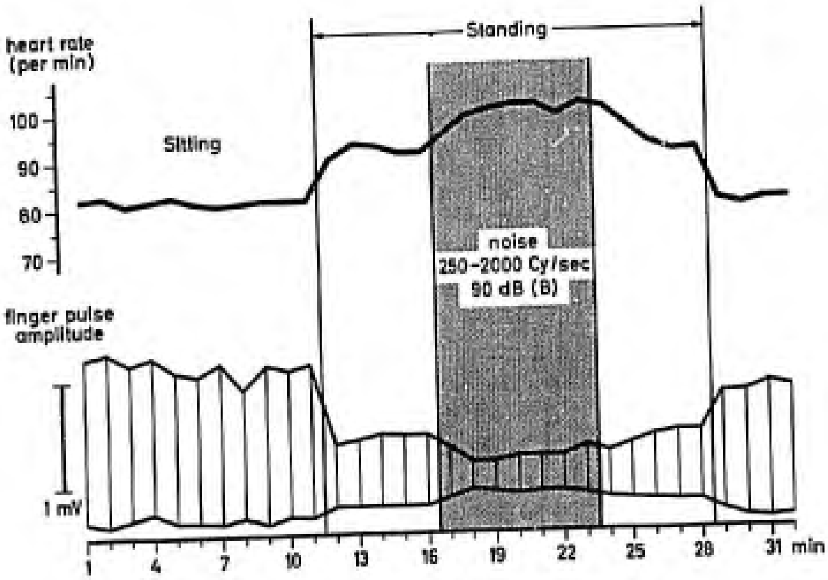

Figure 8, amplitude of volume pulse on finger (method by BOUCKE and BRECHT (8)) and heart rate during 26,2°C$_{eff}$ while sitting and standing. Shaded area = time with noise of 90 dB (B) 250 - 2000 Hz.

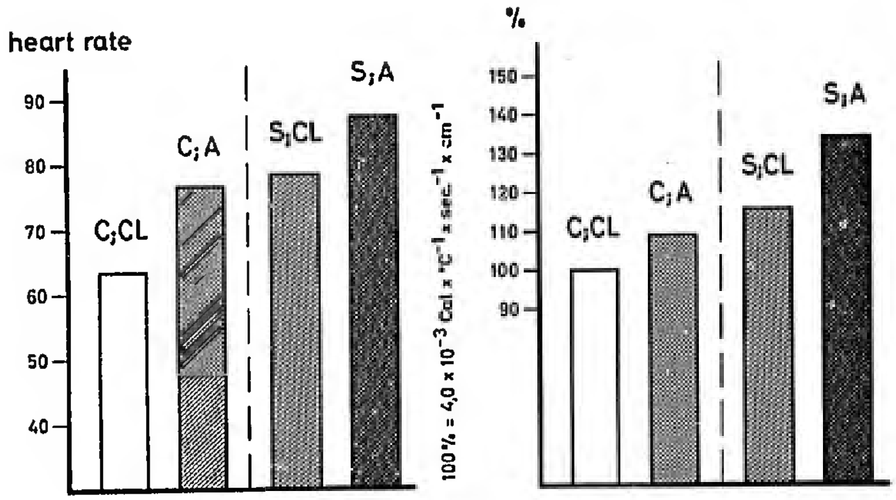

Figure 9, heart rate (left side) and skin temperature conductivity (according to HENSEL (6)) (right side) while seated on a chair (C) and on a stool (S) without activity. Measurements in ambient climate (A): 30,1°C, 73 % R.H. and in a climatized room (CL): 22,9°C, 62 % R.H. (10 subjects).

DISCUSSION:

When interpreting the findings, thinking in closed loops appears to be helpful. In the changes of the blood circulation during these examinations the control of body temperature and vigilance were concerned and interfaced. In this context it may be permissible to consider vigilance as a physiologically controlled magnitude. Body temperature, vigilance, and rise of arterial pressure are provided with a regulating device in the peripheral circulation. Comprehensive publications by HENSEL (9) are available on the close interrelationship between blood pressure control and temperature.

In a hot climate the peripheral vasculatory system is dilated as compared to that in a cooler climate: the peripheral volume pulse is higher, the mean arterial pressure smaller and the heart rate is raised. This regulation device, the peripheral circulation, is influenced by the sympathico-neural impulses through vigilance or noise stimuli in a hot climate, i.e. in the same direction and relative to the initial magnitude of the regulating device, just as in the cooler climate. Vigilance is termed by DEFAYOLLE (10) among others as an increased nervous activity for the perception of information. It became manifest through a noradrenergetic reaction: with an elevated peripheral vasotonus and, in the climate in which the studies were performed, namely between 14 and $27^{\circ}C_{eff.}$, with a decrease of the heart rate. We consider this to be the response via pressure receptors to the increase of the peripheral circulatory resistance. The respiratory frequency under vigilance rises about 70 % above the value at rest and thus indicates a high degree of tension.

Contrary to this we noted a continuous increase of the heart rate in the hot climate which persisted throughout the vigilance activity if same was connected with an elevation of the energy metabolism. The continuous pulse rate increase could not be conditioned on energy since energy metabolism also in the hot climate remained far within the steady state. We interpret the frequency increase as a controlling effect of thermoregulation, caused by a limited heat emission, for in a hot climate with an elevated energetic metabolism under vigilance the peripheral vasotonus remained increased. Consequently the volume pulse was smaller than during the period of nonactivity. The continuous increase of the heart rate may be interpreted as a sign of disregulation. It led to a diminishing of vigilance and technically was seen as a prolonged working time which the subjects needed to perform the same number of tasks in a hot climate as compared to the working time in a cooler climate.

As for noise stimuli, an increase of the peripheral circulatory resistance has been reported OPPLIGER and GRANDJEAN (11), JANSEN (12) MEYER-DELIUS and QUEREDO PUCHE (13), MEYER-DELIUS (14).

The afferent pathways of the sensory organs connect the activating system with the vegetative center. The pulse rate during noise indicated in part an increase and partly a decrease. We consider the effects of sound to be an accentuation of the vigilance tension level and always noticed it as an increase of the peripheral vasotonus. In the present measurements in hot and in cooler climate we noticed partly a decrease and partly an increase of the heart rate. In our opinion heart rate is the resultant of various regulatory functions also in this case. In the present studies its increase may be interpreted as a limitation of the heat convection. We tried to preclude components of psychic irritations.

The deliberations presented in this paper should induce us, also with respect to the effectiveness of vigilance, to exercise caution not to exceed the upper limits of the climatic comfort zone, and if possible, to keep clear off excessive optical and acoustical stimuli and to keep the energetic metabolism during vigilance activities at a low level. At working places under aggravating climatic conditions only persons with an unimpaired cardiovascular system should be employed for vigilance activities, even though they imply only a small amount of muscle activity.

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THE USE OF PHYSIOLOGICAL PROTECTIVE MANEUVERS IN HIGH ACCELERATION ENVIRONMENTS

S. J. Shubrooks, Jr., Major, USAF, MC
S. D. Leverett, Jr., Ph. D.
USAF School of Aerospace Medicine
Biodynamics Branch (SMB)
Brooks AFB, Texas, 78235

SUMMARY

In the studies reported in this paper, the physiological effects of voluntary maneuvers used for protection against $+G_z$ acceleration were investigated. Twenty-five experienced subjects were studied on the USAF School of Aerospace Medicine human centrifuge. During both 15-sec. and 45-sec. rapid onset (1G/sec.) $+G_z$ exposures, the increases in tolerance achieved with the Valsalva straining maneuver (forcefully exhaling against the completely closed glottis) were found to be equivalent to those achieved with the M-1 maneuver (forcefully exhaling against the partially closed glottis), either combined with use of an anti-G suit or without the suit during generalized muscular tensing. Directly measured head level arterial pressure responses correlated with these findings. The use of positive pressure breathing, at levels of 25-40 mm Hg, was also found to result in increases in tolerance, both with and without use of the anti-G suit, at least equal to those obtained with the M-1 maneuver with less accompanying discomfort and fatigue.

With the development of new, high-performance aircraft, it has become increasingly important to establish maximally effective G protective systems. Since physiological protective maneuvers are required in addition to use of the anti-G suit during high $+G_z$ exposures, the effects of these maneuvers on the pilot require investigation. In proposed sustained high $+G_z$ maneuvering environments, where man is at or near the limits of his tolerance, the physiological effects of any maneuver he performs become critical, yet little data are available on the responses to methods commonly used to increase tolerance under such stresses. In this report, the effects of voluntary maneuvers used for anti-G protection will be described. The M-1 maneuver (forcefully exhaling against the partially closed glottis combined with generalized muscle tensing) remains the standard and only generally accepted means of voluntarily increasing G tolerance. The somewhat similar Valsalva maneuver (forcefully exhaling against the completely closed glottis) is widely regarded as detrimental during $+G_z$ exposures because of its greater adverse effect on venous return to the thorax. However, in our experience, pilots evaluated in the Biodynamics Branch at the USAF School of Aerospace Medicine appeared to perform a variety of straining maneuvers - M-1, Valsalva, or some combination of these - with variability of effectiveness. It was therefore felt that the response to the Valsalva maneuver, as opposed to the M-1, must be clearly documented. These studies will be described in the first section of this report.

Because of the variability in effectiveness of both the M-1 and Valsalva, and because of the physical exhaustion caused by either of these maneuvers when continued over long periods, any other procedure capable of similarly raising tolerance with reliability and requiring less effort could be of great value. Increasing intrathoracic pressure by means of positive pressure breathing (PPB) appeared to offer such a possibility and has the advantage of requiring little modification of present aircraft systems. Studies on the effectiveness of PPB will be described in the second section of this report.

The Valsalva Maneuver

Methods.

Studies were performed on ten healthy male volunteer subjects. All were members of a panel of experienced centrifuge subjects and had recently passed a USAF Class III flight physical examination. The first 6 subjects were exposed to $+G_z$ acceleration on the USAF School of Aerospace Medicine human centrifuge under 4 different conditions: (1) control - relaxed with no anti-G protection; (2) during a Valsalva maneuver combined with generalized muscle tensing; (3) during use of a standard USAF CSU-12/P anti-G suit inflated with a standard anti-G valve without muscular tensing; and (4) during performance of a Valsalva maneuver combined with suit inflation and generalized muscle tensing. When the Valsalva maneuver was used, the first maneuver was begun during onset of acceleration. Four subjects repeated the maneuver approximately every 5 to 7 seconds as is done with the M-1. The other two subjects were instructed to hold each Valsalva as long as possible until discomfort required them to repeat it. When maneuvers were repeated, each maneuver was ended with a rapid exhalation followed by rapid inhalation and initiation of the next maneuver. During all Valsalva maneuvers, the subjects were instructed to generally tense their muscles to make this procedure comparable to the M-1.

All acceleration exposures consisted of rapid onset (1G/sec.) runs to a chosen G level (determined by an accelerometer mounted at mid-chest level), with maintenance of that level for 15 seconds unless symptoms of visual impairment required termination of the run at an earlier time. Visual symptoms were determined using a display of a central red light and two peripheral green lights at a distance of 30 inches in front of the subject. The G level at which peripheral light loss (PLL) and central light dimming (CLD) occurred was used as an endpoint for all runs, since this has proved to be highly reproducible and avoids the hazards of blackout and unconsciousness. In most cases, an endpoint could be determined for each condition in 1 to 3 runs, and no more than 5 runs for each condition were carried out to prevent fatigue. Between runs, the heart rate was allowed to return to its control resting level and the subject was allowed to rest as long as desired before proceeding to the next run.

The final 4 subjects were exposed to runs of the same rapid onset but of longer duration - 45 seconds. One (subject G) was studied without an anti-G suit; and 3 (subjects H to J), with the suit. After control endpoints (without the suit in the 1 subject and with the suit in the other 3) had been obtained during

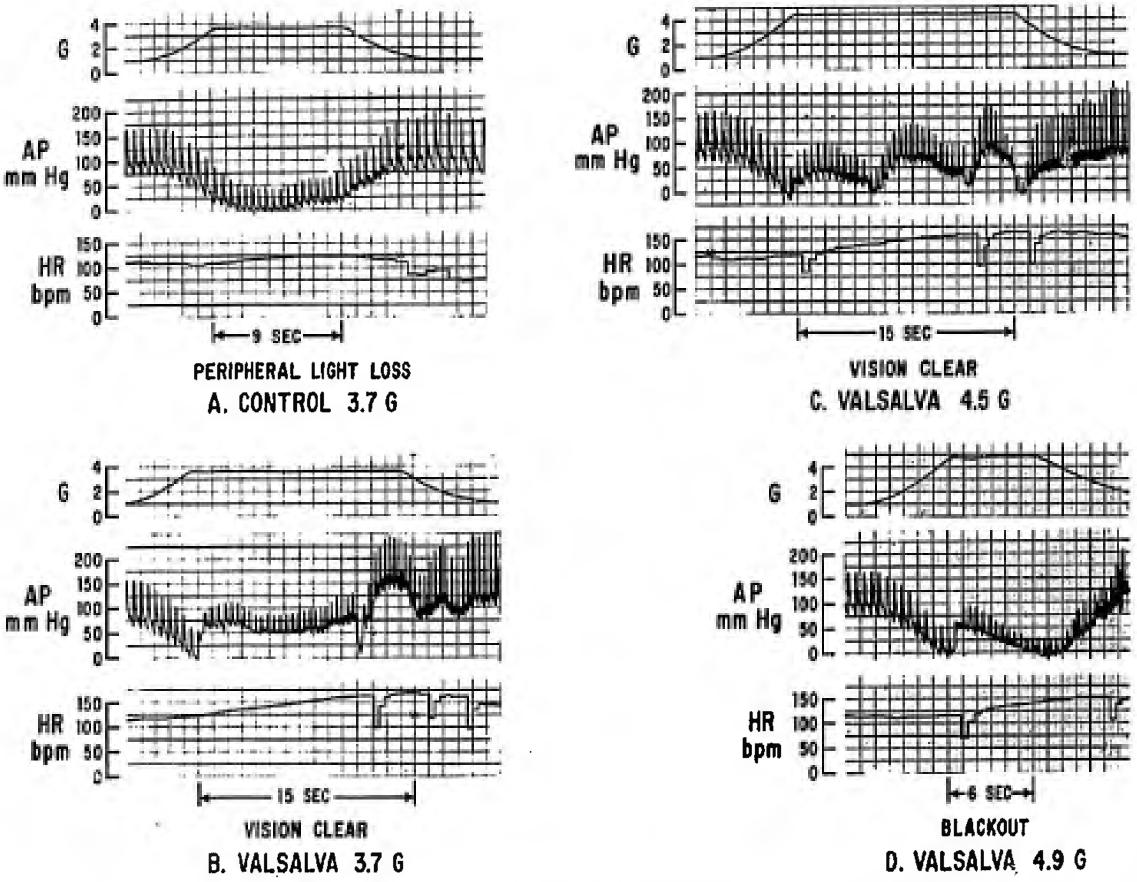
TABLE 1

$+G_z$ levels at which endpoints occurred. (Visual symptoms at each endpoint shown in parentheses.)

Subject	Control	Valsalva Without Suit	Suit Alone	Suit + Valsalva
A	3.1 (PLL-9 sec.)	4.0 (PLL-10 sec.)[1]	4.5 (PLL-5 sec.)	5.2 (PLVD-11 sec.)[5]
B	3.9 (PLVD-7 sec.)	5.2 (PLL-7 sec.)	6.1 (NVS-15 sec.)[4]	6.3 (NVS-15 sec.)[4]
C	4.4 (PLL-14 sec.)	5.1 (PLL-14 sec.)[2]	5.4 (PLL-15 sec.)	7.0 (NVS-15 sec.)[6]
D	3.3 (PLL-9 sec.)	3.9 (PLL-6 sec.)	4.6 (PLL-11 sec.)	6.2 (PLL-7 sec.)[7]
E	4.3 (PLL-6 sec.)	5.0 (NVS)[3]	5.3 (PLL-4 sec.)	6.8 (NVS-15 sec.)[8]
F	3.7 (PLL-9 sec.)	4.9 (B.O.-6 sec.)	5.2 (haze-15 sec.)	6.7 (PLD-6 sec.)[9]

Abbreviations: PLL = peripheral light loss; PLD = peripheral light dim; PLVD = peripheral light very dim; B.O. = blackout; NVS = no visual symptoms.

1. PLL during long inhalation; AP 60/27 just before centrifuge stopped.
2. PLL at end of single Valsalva held for 14 sec.
3. AP did not fall below 86/65 except during the one inhalation when peripheral lights dimmed slightly.
4. With suit alone at 6.1G and with suit + Valsalva at 6.3G, peripheral lights were approximately 50% dimmed early in run only, followed by complete clearing of vision; AP's were at most times higher during the Valsalva run. Valsalva maneuver was not well performed.
5. PLVD during prolonged inhalation at 11 sec.; full run was completed and AP had increased to 65/40 just before centrifuge stopped at 15 sec.
6. AP never less than 60/45 and was 120/80 at end of run. No further runs were performed because of fatigue.
7. PLL during prolonged inhalation at 7 sec.; AP had increased to 75/25 just before centrifuge stopped.
8. AP at no point lower than 75/55 and had reached 182/120 during third Valsalva just before end of run. No further runs performed because of fatigue.
9. Peripheral and central lights approximately 50% dimmed during inhalation.



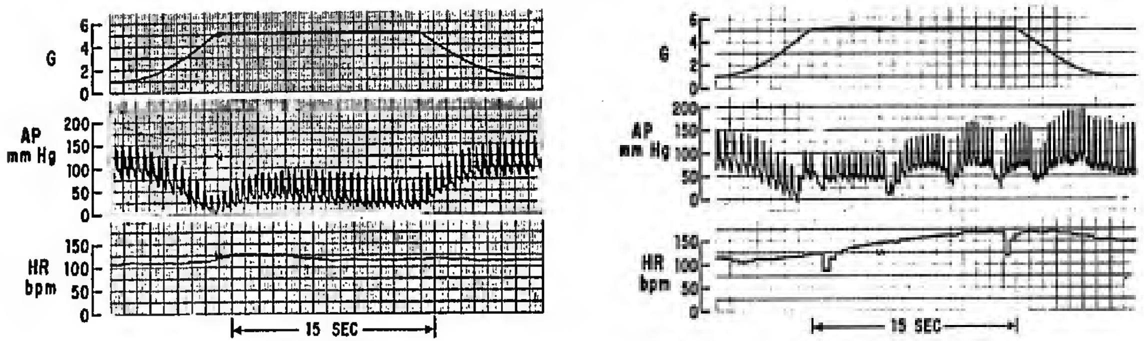
PERIPHERAL LIGHT LOSS
A. CONTROL 3.7 G

VISION CLEAR
C. VALSALVA 4.5 G

VISION CLEAR
B. VALSALVA 3.7 G

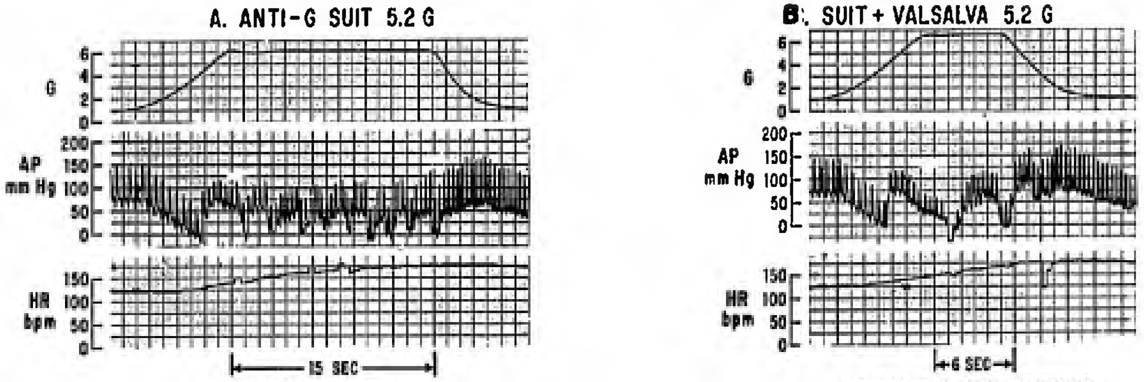
BLACKOUT
D. VALSALVA 4.9 G

Figure 1. Subject F. Valsalva maneuver without anti-G suit.



OVERALL HAZE
A. ANTI-G SUIT 5.2 G

VISION CLEAR
B. SUIT + VALSALVA 5.2 G



VISION CLEAR
C SUIT + VALSALVA 6.2 G

MODERATE OVERALL DIMMING
D. SUIT + VALSALVA 6.7 G

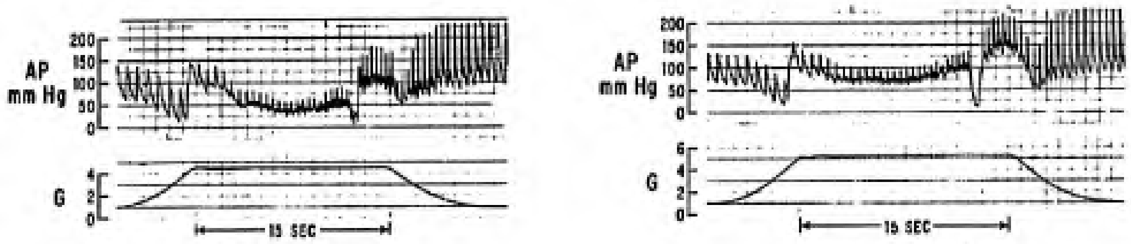
Figure 2. Subject F. Valsalva maneuver with anti-G suit.

WITHOUT ANTI-G SUIT

WITH ANTI-G SUIT

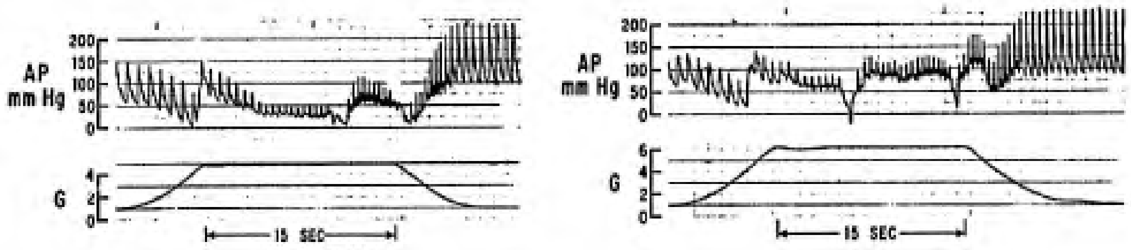
PERIPHERAL LIGHT LOSS
A. CONTROL 4.3 G

PERIPHERAL LIGHT LOSS
D. ANTI-G SUIT 5.3 G



VISION CLEAR
B. VALSALVA 4.6 G

VISION CLEAR
E. SUIT + VALSALVA 5.3 G



VISION CLEAR
C. VALSALVA 5.0 G

VISION CLEAR
F. SUIT + VALSALVA 6.3 G

Figure 3. Subject E. Valsalva maneuver without and with anti-G suit.

15-sec. runs, each was studied at a G level 0.5G higher than his control endpoint. At that level, two 45-sec. runs were performed, one with the Valsalva and one with the M-1. In addition, two 45-sec. runs with the Valsalva and M-1 were performed at 1.0G over control in subject G, 1.8G over control in subject I, and 2.0 and 3.0G over control in subject J. The subjects were allowed to rest as long as desired (a minimum of 10 minutes) between runs.

Direct arterial pressure (AP) was measured on all subjects (except subject J) using an 18-gauge Teflon arterial needle inserted in the left radial artery. The left arm was elevated and supported with the wrist at eye level and the needle was connected by a short polyethylene catheter to a Statham P-37 miniature strain gauge transducer firmly mounted on subject's helmet at the level of the outer canthus of the eye and oriented so as not to be affected by the gravitational field. ECG was monitored continuously on all subjects using a sternal and biaxillary lead system, and voice communication and closed-circuit television monitoring were maintained at all times.

Results.

Results for subjects A to F are summarized in Table 1. Because of difficulties in reaching exactly similar endpoints under all conditions in each subject, as described in footnotes to Table 1, and because of differences in each subject's performance of the Valsalva maneuver (see Discussion), it is not possible to present a meaningful value for the maximum increase in G tolerance which can be attained with the Valsalva. However, in all cases both with and without use of the anti-G suit, $+G_z$ tolerance was clearly increased by use of this maneuver. Without the suit, the increase in tolerance ranged from 0.6G in subject D (who was the least well-developed physically and strained considerably less during the Valsalva than did the other subjects) to 1.5G in subject F. With the exception of subjects A and B, when the Valsalva was combined with the suit, the G level achieved was greater than 1.5G over that reached with the suit alone, and at least in subjects C and D, levels 2G higher than with the suit alone could probably have been well tolerated.

Data from subject F, both without and with the anti-G suit, are shown in Figures 1 and 2, respectively. In Figure 1B and 1C and in Figure 2B-D, the AP response to repeated Valsalva maneuvers is well demonstrated. For this subject, as well as for all others who performed repeated maneuvers, AP was seen to rise progressively with each successive maneuver. The only exception to this finding was subject F's run at 6.2G (Figure 2C) in which maneuvers were repeated approximately every 2 seconds and AP reached the same level with each maneuver instead of progressively increasing. In general, the increment in AP with successive maneuvers appeared dependent on the time for which the preceding maneuver was held, being greatest when the preceding Valsalva was held for a longer period of time (as in Figure 1B). When the Valsalva was held for 5 to 8 seconds, increase in AP with the following Valsalva over that of the preceding one, at the same constant G level, ranged from 12 mm Hg systolic/12 mm Hg diastolic to 75/45, with an average increase of 45/30. When the maneuver was held longer, for 9 to 11 seconds, this increase ranged from 25/15 to 150/135, with an average of 65/45. In some, but not all, subjects greater elevations of AP could be achieved with a Valsalva when combined with a suit than when used alone. Some subjects maintained AP at a constant level throughout the Valsalva while others showed a slight decrease in AP as the Valsalva was held, this decrease appearing to be related to a decrease in the amount of straining during the maneuver.

When a single Valsalva maneuver was held throughout or through most of a run (all runs in subjects B and C and some in subject F), a marked increase in AP was seen. Either with or without the suit, during these prolonged Valsalva maneuvers AP almost always, with small variations, remained constant throughout the maneuver (as shown for subject E in figure 3). Occasionally, a small decrease in AP occurred near the end of a prolonged Valsalva, but AP always remained markedly higher than during the control run until G levels considerably above that of the control run were reached.

TABLE 2

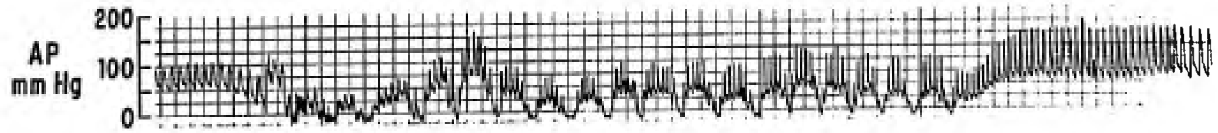
Summary of 45-sec. $+G_z$ exposures and visual symptoms.

Subject	Control	Valsalva	M-1
G - No suit	3.9 (PLVD-15 sec.)	4.4 (NVS) 4.9 (NVS)	4.4 (NVS) 4.9 (NVS)
H - Suit	4.9 (PLL-9 sec.)	5.4 (NVS)	5.4 (NVS)
I - Suit	5.2 (PLVD-15 sec.)	5.7 (NVS) 7.0 (NVS)[1]	5.7 (NVS) 7.0 (PLVD at onset only)[1]
J - Suit[2]	5.0 (PLD-15 sec.)	6.0 (NVS) 7.0 (NVS) 8.0 (NVS)	6.0 (NVS) 7.0 (NVS) 8.0 (NVS)

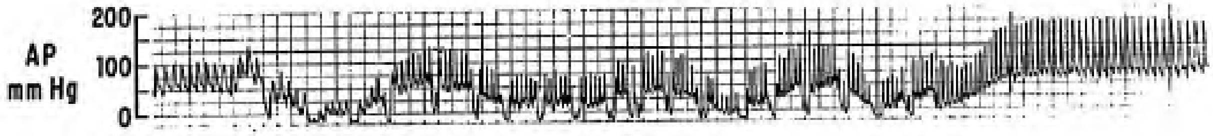
Abbreviations: PLL = peripheral light loss; PLVD = peripheral light very dim; PLD = peripheral light dim; NVS = no visual symptoms.

1. Both 7.0G runs for this subject were only 36 sec. in duration since the centrifuge was accidentally stopped at this point during the Valsalva run; no visual symptoms occurred.

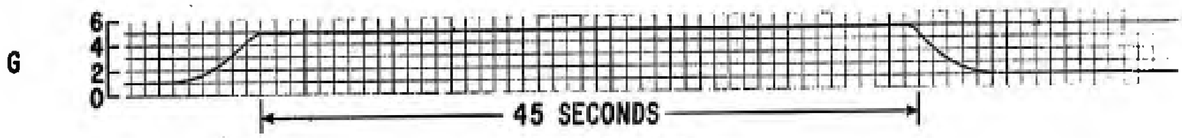
2. In this subject, Valsalva and M-1 runs were performed on separate days to avoid fatigue from the large number of high-G exposures.



VALSALVA MANEUVER

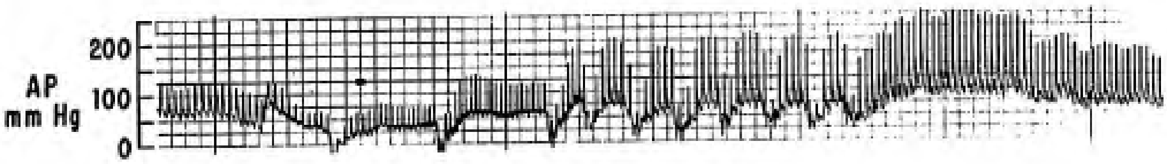


M-1 MANEUVER

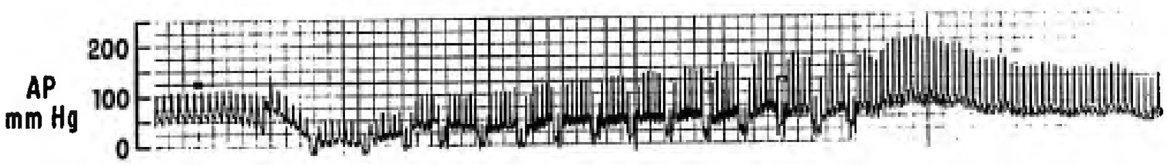


4.9 G

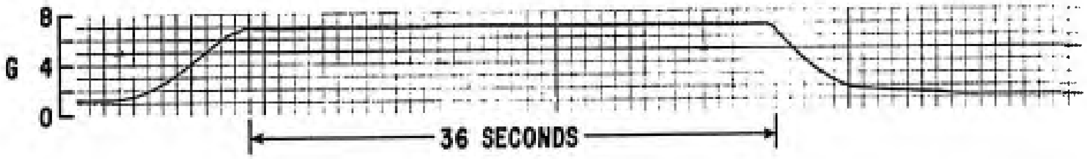
Figure 4. Subject G. Arterial pressure response during prolonged $+G_z$ exposures with anti-G suit.



A. VALSALVA



B. M-1



7.0 G

Figure 5. Subject I. Arterial pressure response during prolonged $+G_z$ exposures with anti-G suit.

A summary of the longer 45-sec. runs is shown in Table 2. In all cases, the entire run was completed, and no runs were limited by visual symptoms. Runs at higher G levels were not carried out because of the subjects' fatigue. AP response during the 4.9G run of subject G without an anti-G suit is shown in Figure 4. Figure 5 shows AP response during the 7.0G run of subject I with the suit. Data during all other runs were not different from those shown in these figures. Although level of AP varied from maneuver to maneuver, depending on the intensity with which the subject strained to perform either the Valsalva or M-1, it is obvious that a level of AP can be attained with the Valsalva which is at least equal to that achieved with an M-1 maneuver, even when continued over a period of 45 seconds.

Discussion.

The M-1 maneuver is the long-accepted means of increasing tolerance to $+G_z$ acceleration either with or without use of the anti-G suit. The Valsalva maneuver, to the contrary, is widely considered to be detrimental to $+G_z$ tolerance, although little evidence exists to support this belief. Wood and Lambert (1) have reported results of two 15-sec. centrifuge runs without an anti-G suit during which a marked decrease in AP occurred with performance of a Valsalva maneuver at 3.0G and 3.5G, resulting in unconsciousness in the former and PLL in the latter; other runs using an anti-G suit were reported to show an increase in tolerance with the Valsalva. It is widely accepted that the M-1 maneuver permits continuing venous return from the lower body by maintaining an abdominal-thoracic pressure gradient not present during the Valsalva.

The present study, however, clearly indicates that the Valsalva maneuver is effective in increasing $+G_z$ tolerance either in conjunction with an anti-G suit or without the suit if combined with muscle tensing to make this maneuver comparable to the M-1 as performed by the pilot. Because few pilots in existing aircraft would be required to sustain high-G exposures for longer than 15 sec., this time period was used for the initial portion of the study. It was questioned, however, whether repeated Valsalvas continued for a longer period of time would result in a lowering of AP and of G tolerance. The longer exposures were therefore carried out and showed that, at least for periods of up to 45 seconds, no decrement in AP with time occurred. Although a single Valsalva maneuver held for as long as 15 seconds did not result in a significant fall in AP when done in conjunction with muscle tensing or suit inflation and resulted in increased G tolerance, such a prolonged maneuver does not permit the overshoot and progressively increasing AP accompanying repeated maneuvers and therefore should not be as effective as a G protective maneuver. Obviously, if held sufficiently long, the Valsalva will result in syncope.

It was not the purpose of this study to determine the maximum possible protection which could be attained with the Valsalva but to demonstrate that this maneuver results in AP responses similar to the M-1 and an increase rather than a decrease in $+G_z$ tolerance. It is certain that had the subject had more extensive training and practice in performing the Valsalva, greater increases in tolerance would have been observed. No M-1 maneuvers were included during the early shorter runs in this study because of the larger number of exposures which would have resulted, but comparison was possible during the 45-sec. runs. Furthermore, the G protection achieved with the Valsalva was comparable to that provided in our experience by the M-1 with a similar amount of subject training. Visual symptoms and AP responses were not different from those seen in other studies with the M-1, both with and without use of the anti-G suit.

Positive Pressure Breathing

Methods.

Studies were performed on 15 volunteer subjects, experienced members of the centrifuge panel as previously described. The same rapid onset (1G/sec.) $+G_z$ runs were used with PLL again as the endpoint. Since no mask was available which would permit the desired levels of pressure breathing without excessive air leak, PPB was performed using a noseclip and a flexible tube with a mouthpiece connected to a pressure regulator.

This study was conducted in two parts. Phase I included 5 subjects exposed to 15-sec. runs. After a control endpoint had been established during a relaxed unprotected run as described previously, each subject was studied under the following four conditions imposed in a varying order designed to prevent any one condition from consistently affecting the response to subsequent conditions: (1) PPB with room air at approximately 25 mm Hg for 20 to 30 seconds preceding and during acceleration; (2) PPB with 5% CO_2 at approximately 25 mm Hg for 20 to 30 seconds preceding and during acceleration; (3) breathing of 5% CO_2 at atmospheric pressure for 60 seconds preceding and during acceleration; and (4) the respiratory component only of the M-1 maneuver (muscle tensing omitted for comparison with PPB without muscle tensing). Additional runs with PPB at 35 mm Hg were performed by 3 subjects who were capable of doing this. Eye-level arterial pressure was measured in these subjects as previously described.

Phase II included 10 additional subjects who were accustomed to high G exposures (two were experienced jet fighter pilots) and who were trained to a greater extent than the previous group in performing the M-1 maneuver and PPB. With this group, the runs were extended to 30 seconds at peak G, with the same 1G/sec. onset rate. After a control endpoint had been determined, as with the previous group, these subjects were studied under the following two conditions, the order of these being alternated: (1) the M-1 maneuver; and (2) PPB with room air at a higher breathing pressure of approximately 40 mm Hg, this time combined with generalized muscle tensing to make this procedure comparable to the full operational M-1 maneuver. AP was not measured during these runs. Two of this latter group of subjects (numbers 3 and 4) and one additional subject were also studied with PPB (40 mm Hg) combined with the anti-G suit. Fifteen-second runs with PPB begun 15 seconds prior to the run were used in this portion of the study.

Results.

In Phase I during the 20 to 30 seconds of PPB prior to the onset of acceleration, systolic AP during the expiratory phase increased from 17-40 mm Hg and diastolic AP increased 15-32 mm Hg (an average increase of 27 and 21 in systolic and diastolic pressures, respectively). During the inspiratory phase, systolic AP fell nearly to, or occasionally below, control systolic pressure, although diastolic AP always remained above the control level. Results during acceleration are shown in Table 3 as increases in G tolerance compared to control runs (differences between G levels at which PLL occurred). Subjects A and B, whose tolerance was increased by only 0.4G and 0.5G, showed the poorest response of AP to PPB and the most marked falls in AP during the inspiratory phase, both probably due to inadequate technique of pressure breathing. The remaining subjects showed increases in tolerance of 0.8, 1.0, and 1.6G.

When any given subject was exposed during PPB to the same G level which had caused PLL during the control run, both systolic and to a greater extent diastolic AP's were increased above those of the control run and no visual symptoms occurred. As the G level was then increased, systolic pressure progressively fell below but diastolic pressure remained above the respective systolic and diastolic pressures at which PLL had occurred in the control run. No visual symptoms occurred at these progressively higher G levels until diastolic AP finally fell approximately to the diastolic AP at which PLL had occurred during the control run, and at that point PLL also occurred during PPB. In the three subjects for whom the higher 35 mm Hg breathing pressure was used, G tolerance showed very little further increase. However, it was more difficult for these subjects to perform pressure breathing at this level, and a greater change may well have been seen had the subjects had more practice in pressure breathing at the higher levels.

TABLE 3

Increases in $+G_z$ Tolerance Over Control Levels - Phase I

Subject	PPB 25 mm	PPB 35 mm	PPB-CO_2	M-1	CO_2
A	0.5	-	0.8	0.5	0.5
B	0.4	0.7	0.7	0.4	0
C	1.6	1.8	1.6	1.0	1.0
D	0.8	0.8	0.8	0.6	0
E	1.0	-	1.0	>0.8[1]	0.5

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[1] No endpoint reached; no further runs performed because of subject's fatigue.

As shown in Table 3, when PPB was combined with 5% CO_2, 3 subjects showed no difference in G tolerance as compared to PPB alone; AP responses in these subjects were the same under both conditions. Two subjects had a slight (0.3G) increase in tolerance with PPB in combination with CO_2 and these 2 showed higher AP responses to the CO_2 pressure breathing both before and during acceleration. Increased G tolerance therefore appeared dependent on the AP response. Whether this was due to the effect of the CO_2 or to differences in technique of pressure breathing remains unresolved.

The respiratory component of the M-1 maneuver resulted in an increase in G tolerance equal to that of PPB in 2 subjects, less than that of PPB by 0.6 and 0.2G in 2 subjects, and greater than that of PPB in 1 subject (Table 3). All subjects appeared to be performing an adequate M-1 maneuver although the difference in results may be due to differences in ability to perform the maneuver well and to differences in the amount of muscle tensing. AP changes were similar to those during PPB.

Effects on G tolerance of CO_2 breathing at atmospheric pressure were variable as shown in Table 3. Two subjects showed no difference from control runs, while 3 showed increases in tolerance of 0.5 to 1.0G. As with use of CO_2 with PPB, an increased tolerance was found only when the CO_2 breathing had resulted in an increase in AP both prior to and during acceleration.

TABLE 4

Increase in $+G_z$ Tolerance Over Control Levels - Phase II

Subject	PPB	M-1
1	1.0	1.0
2	1.4	1.2
3	0.8	1.6
4	1.0	2.3
5	2.2	1.7
6	1.2	1.3
7	1.4	1.7
8	1.0	0.5
9	0.7	2.0
10	1.3	1.0
mean	1.2	1.4

For Phase II, increases in G tolerance during PPB and M-1 maneuvers, as compared to the control runs (differences between G levels at which PLL occurred), are shown in Table 4. With PPB, with the exception of 2 subjects, tolerance increased by 1.0 to 2.2G. These two, with increases of 0.7 and 0.8G, did not perform PPB technically well and experienced marked inspiratory fall in airway pressure. The variability in effectiveness of the M-1 also appeared to be related to the subject's mastery of this maneuver; the subjects who showed the greatest increase in tolerance with the M-1 (subjects number 3, 4, and 9) performed the best maneuver as judged by visual observation during the runs.

Although some subjects showed more protection from the M-1 and others more from PPB, analysis of the grouped data showed no significant difference between the G protection afforded by PPB and that provided by the M-1 maneuver. However, all but one subject felt that if both procedures had to be sustained over a 30-second period, PPB, even at levels of 40 mm Hg, was easier to tolerate than the repeated M-1 maneuvers, which became extremely exhausting.

Of the 3 subjects studied with PPB combined with the anti-G suit, 2 completed the 15-sec. runs at 8.5G. Higher G levels were not attempted. PLL occurred at 8.0G in the other subject, but he had a mild upper respiratory infection at the time and experienced some difficulty with pressure breathing. All three of these subjects had, with extensive training, been able to reach 9.0G with the M-1 maneuver and the anti-G suit. All felt that the counter-pressure afforded by the suit made the pressure breathing very much easier to perform.

Discussion.

As intrapulmonary pressure increases with pressure breathing, there is an almost equal increase in intrapleural pressure, which is applied to the heart and intrathoracic vessels, and systolic and diastolic AP rapidly increase at the onset of pressure breathing by an amount nearly equal to the increase in intrapleural pressure. Although venous return from the brain (because of the rigidity of the skull), and from the abdominal viscera (because of the accompanying increase in intra-abdominal pressure) probably continues, that from the limbs ceases because of the increase in intrathoracic pressure and begins again only when the increase in limb venous pressure from continued arterial inflow exceeds intrathoracic pressure. The decrease in central blood volume, cardiac output, and arterial pulse pressure resulting from the decrease in venous return is then, through the carotid sinus baroreceptors, followed by a reflex systemic arteriolar vasoconstriction and an increase in mean arterial pressure. This baroreceptor response continues to occur in spite of the increased mean arterial pressure, since the decreased pulse pressure appears to be a more effective stimulus to the baroreceptors than is mean arterial pressure. Also, the intrathoracic baroreceptors continue to be exposed to a decreased transmural pressure due to the increased intrathoracic pressure. The level of mean arterial pressure reached during this phase for a given airway pressure appears to be highly correlated with training in performance of pressure breathing. Although PPB is known to result in these changes without acceleration, its effects during the marked hemodynamic changes occurring with $+G_z$ acceleration remain unstudied. The increase in mean arterial pressure at head level would be expected to increase $+G_z$ tolerance. However, whether this effect would be counteracted by the decrease in cardiac output cannot be predicted.

The data obtained from this study clearly indicate that PPB is an effective means of increasing $+G_z$ tolerance both with and without use of the anti-G suit for periods of up to 30 seconds, and that the amount of protection attained is approximately equivalent to that provided by the M-1 maneuver when an equal amount of training has been given in performance of both maneuvers. In conjunction with the anti-G suit, pressure breathing was noticeably easier to perform and, as expected, because of the limitation of venous pooling in the lower extremities and the effect of abdominal counterpressure in further increasing intrapleural pressure, resulted in a greater increase in tolerance than when used without the suit. It is therefore apparent that, in spite of the decrease in cardiac output which almost certainly occurs, the increase in diastolic AP is sufficient to increase cerebral blood flow and G tolerance. Although PPB in these studies was begun 15-30 seconds prior to acceleration, the AP response occurred within a few seconds of onset of pressure breathing and such an initial period of PPB before acceleration exposure should not be required.

Unfortunately, the use of a mouthpiece and noseclip in these studies made pressure breathing somewhat uncomfortable. A well-fitting mask capable of maintaining these pressures would probably have resulted in greater increases in tolerance. Training and experience in performing pressure breathing also plays an important role in its effectiveness in raising AP. It is probable that had these subjects, most of whom had had no previous experience, been more extensively trained, further protection would have been achieved.

Elevation of inspired P_{CO_2} might also be anticipated to increase $+G_z$ tolerance by increasing AP secondary to systemic vasoconstriction, by causing local cerebral vasodilatation, or by its effects on the oxyhemoglobin dissociation curve. Gauer in 1945 (2) reported a variable increase of approximately 10% in $+G_z$ tolerance with 10 minutes of 6% CO_2 breathing and recommended addition of CO_2 to aircraft oxygen systems but little attention has been given since to this possibility. In the present studies, any increase in tolerance appeared to be dependent on the AP response alone and not on local effects on the cerebral circulation. This may be explained by lack of a significant effect of CO_2 on cerebral blood flow at the very low AP's at which visual symptoms occur with acceleration. However, the increases in tolerance found with some subjects may warrant further study.

The AP response of PPB is very similar to that of the Valsalva and M-1 maneuvers, the primary difference being in respiratory variations in AP and blood flow dependent on the relative duration of the inspiratory and expiratory phases and the intrapleural pressures attained during each. With PPB, intrapleural pressure remains elevated throughout the maneuver, although perhaps at lower airway pressures than reached intermittently with the M-1 or Valsalva. This continuously elevated intrathoracic pressure eliminates the sudden marked fall in AP during inhalation which occurs with the M-1 and Valsalva, but some critical combination of pressure and time will undoubtedly result in sufficient impedance to venous return to cause syncope. Therefore, it remains to be determined exactly what type of respiratory maneuver will provide the optimum level and time course of airway pressure to result in the maximum possible increase in $+G_z$ tolerance. Another important consideration is the energy expenditure required to perform such a maneuver, an important factor for the pilot who may encounter frequent repetitive acceleration exposures.

In this regard, it is interesting that nearly all subjects in this study felt that PPB was considerably easier to perform and less exhausting than repeated M-1 maneuvers, particularly during the longer acceleration exposures.

References.

1. Wood, E. H., and E. H. Lambert. J. Aviat. Med 23: 218-228, 1952.

2. Gauer, O. H. The Physiological Effects of Prolonged Acceleration. IN: German Aviation Medicine World War II, Vol I, Dept. of the Air Force, Washington, D. C., 1950, p. 581.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-8.

GENERAL DISCUSSION

CLARKE I would like now to call on your Co-Chairman, Dr. Grether, for his general remarks and conclusions regarding the papers we have heard today as they pertain to the overall topic of combined stress. Dr. Grether has been involved with much of the thinking in the USAF on this subject in recent years and has been principle investigator on recent related research.

GRETHER Today's presentations and discussions have been excellent and have provided considerable new and important ideas and data for this very complex problem. However, I think the overall picture remains quite confusing and complicated.

From an experimental standpoint, the outcome of stress interaction studies is more than usually dependent on the experimental design. The following seem to have been particularly important in the studies available in the literature:

(a) Stressors: The number and kind of stressors used will obviously be an important consideration.

(b) Intensity: Quite different results can be expected in some cases, depending on the level of stress.

(c) Type of Measurement: Within the broad categories of physiological and behavioral, the type of measure may influence the effect of interactions in the experimental situation.

McCally and Murray (Murray, R. H. and McCally, M. Combined environmental stress. In NASA Bioastronautics Data Book, in press) in our laboratory reviewed about a hundred studies which involved two or more stressors, including both human and animal studies. In the majority of cases there were neither additive nor antagonistic effects measured. Quite a few additive effects and a lesser number of antagonistic interactions were observed. Only a very few studies reported synergistic effects. Here are a few examples of fairly well known interactions: (a) Radiation effects are to some extent countered by concurrent hypoxia (antagonistic effect); hyperoxia and radiation have an additive effect in combination. The basis for these interactions is the common physiologic mechanism acted upon- the hemopoietic system-. (b) Some evidence exists to show that acceleration tolerance is affected by hypoxia; again the explanation of the effect being the physiologic alteration to which both contribute - cerebral and or retinal hypoxia - (c) From the behavioral side, Wilkinson in Great Britain showed an antagonistic effect of noise and sleep loss; the sleepy subject's performance was poor but improved when he was aroused by noise.

I think these examples illustrate the pathway wherein there is some hope of making meaningful progress in this complex area. This is to work towards establishing a fundamental basis for the operationally significant interactions to be studies and to experimentally test postulations of interactions of stressors on this basis.

CLARKE As your Co-chairman and Editor, I would like to thank all the authors for their excellent papers and presentations and thanks also to the group for your active participation in the discussion.

I would like to make one more comment, if you will permit me. Dr. Grether, my Co-chairman, and a member of the AGARD family for many years, is attending his last meeting of this Panel today. He tells me that soon after he gets home he will be retiring. I would like to express the appreciation of the Group, Dr. Grether, for your long years of active support of the AGARD community.