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AGARD ADVISORY REPORT 324

Psychophysiological Assessment Methods

(inc Register of
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AGARD ADVISORY REPORT 324

Psychophysiological Assessment Methods
(including a Register of Psychophysiologists – on microfiches)

Méthodes d'Evaluation Psychophysiologique
(liste de psychophysiologues incluse sur microfiches)

by

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North Atlantic Treaty Organization
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Preface

Determinations regarding the effects of environmental stressors, fatigue, high/low workload, disturbances of circadian rhythms, pharmacological interventions, and sleep disruption on the human operator are difficult to make in almost any situation. However, it is an especially arduous task to study the impact of these factors on personnel engaged in operationally-relevant duties such as planning flight missions, preparing crews and equipment, and piloting aircraft. Testing human subjects in non-standard "real world" environments presents numerous problems and constraints that are often obviated in the laboratory.

It is clear, because of the difficulties in predicting actual operational performance based on limited experiments, that a multidimensional assessment strategy is important to evaluate operators (i.e., aviators, flight crews, etc.) in a comprehensive manner. Toward this end, researchers must take advantage not only of performance tests which evaluate the behavioral output of personnel, but physiological assessments which evaluate the precursors of that output.

Although there has been considerable work towards establishing and standardizing basic performance tests, little has been done to address the use of physiological/psychological measures in aerospace research and development. While the development of a completely standardized psychophysiological assessment battery is problematic due to equipment differences, testing variations, and other changes from one research setting to another, some basic level of comparability across research settings can be established to increase the generalizability or research findings.

One step in this direction would be the availability of an authoritative guide which can be referenced by novice or infrequent users of psychophysiological techniques. This is important because of the increased application of psychophysiological measures in aerospace research. Likewise, such a document can be useful for more established researchers who are interested in implementing new psychophysiological techniques or are new to operational research settings.

This document presents the efforts of North Atlantic Treaty Organization/Advisory Group for Aerospace Research and Development (NATO/AGARD) Working Group 19 toward establishing a comprehensive overview of the psychophysiological techniques available, the types of aerospace research problems in which they may be applied, and the basic rationale, recording procedures, and analytical strategies unique to each measure. Also, the text includes examples of operationally-relevant research in which psychophysiological measures served an integral part. Although the actual implementation of psychophysiological techniques will require more extensive background or training than what can be gained from reading this Advisory Report alone, the information presented here should provide a starting point for investigators interested in using physiological measures. In addition, a register has been assembled containing the names and affiliations of scientists engaged in various types of psychophysiological studies throughout the NATO countries. This has been provided to offer the new or the seasoned psychophysiologist with a reference source which can be relied upon when the implementation of new procedures or the refinement of older procedures is desired.

The report is organized into four chapters which are followed by nine appendixes. The first chapter presents an overview of the rationale for employing psychophysiological techniques and a discussion of the advantages and problems associated with these techniques. The second chapter provides information about the use of psychophysiological measures in the study of operationally-relevant problems such as those stemming from circadian disruptions, environmental stressors, and fatigue.

The third chapter describes the basic attributes of each of the psychophysiological measures most frequently collected and analyzed when studying the problems discussed in chapter 2. The fourth chapter begins with of a discussion of special considerations which must be taken into account when employing psychophysiological techniques and concludes with recent illustrative examples of research projects in which these techniques played a crucial role.

The appendixes present a detailed discussion of the methodology for collection and analysis of each of the psychophysiological measures described in the main body of the report. Each appendix is largely independent, although some commonalities do exist with regard to the various procedures described. If after reading the discussion of a particular measure the reader requires additional information, he/she can consult the register of psychophysiologists in order to locate and expert who is knowledgeable about a particular research area or psychophysiological technique.

Of course there have been volumes written about each of the psychophysiological techniques discussed here, and this report is not intended to be a comprehensive evaluation of each measure. Rather, we have focused upon the unique challenges of applying these techniques in an operationally relevant aerospace environment. Especially in the case of the novice psychophysiologist, this guide should help to alleviate some of the frustration which is often found when transitioning from the basic research laboratory to the realities of the operational world.

Colonel David H. Karney
Chairman
AGARD AMP Working Group 19

Préface

Dans la quasi-totalité des situations, il est difficile de déterminer les effets des éléments stressants ambiants, de la fatigue, des charges de travail excessives/insuffisantes, de la perturbation des rythmes circadiens, des incidences pharmacologiques et des interruptions du sommeil sur l'opérateur humain. Mais il est particulièrement ardu d'étudier l'impact de ces facteurs sur le personnel occupé à des tâches opérationnelles telles que la planification des missions, la préparation des équipages et des équipements et le pilotage des avions. L'évaluation de sujets humains en environnement "monde réel" non-standard présente de nombreux problèmes et contraintes qui peuvent souvent être évités en laboratoire.

Vu les difficultés qui se posent pour la prévision des performances opérationnelles réelles sur la base des résultats des expérimentations limitées qui sont indisponibles, il est clair que l'évaluation des opérateurs (c'est-à-dire des aviateurs, des équipages, etc..) de façon complète passe par une stratégie multidimensionnelle. Avec cet objectif en vue, les chercheurs doivent tirer profit non seulement des tests de performance destinés à évaluer le comportement des personnels, mais aussi des appréciations physiologiques qui permettent d'évaluer les signes précurseurs de ces comportements.

Quoique des efforts considérables aient été faits en vue de l'établissement et la standardisation des tests de performance de base, il n'y a eu que très peu d'activités visant l'application de mesures physiologiques/psychophysiologiques en R&D aérospatiale. Bien que le développement d'une batterie de tests d'évaluation psychophysiologiques totalement standardisés soit problématique en raison des différences qui peuvent exister au niveau des équipements, des méthodes d'essais, et d'autres dissimilitudes possibles entre les différents établissements de recherche, des critères de comparabilité pourraient être établis pour les différents établissements afin de promouvoir la banalisation des résultats de tels tests.

Un pas dans la bonne voie serait l'édition d'un guide qui ferait autorité dans le domaine, pour consultation par des utilisateurs de tests psychophysiologiques occasionnels ou novices. Ceci est important car les mesures psychophysiologiques sont de plus en plus employées dans la recherche aérospatiale. Ainsi, un tel document pourrait être utile aux chercheurs confirmés intéressés par la mise en application de nouvelles techniques psychophysiologiques, aussi bien qu'à ceux qui débutent dans la recherche opérationnelle .

Le présent document représente les efforts du groupe de travail No. 19 du Groupe Consultatif pour la Recherche et les Réalisations Aérospatiales de l'Organisation du Traité de l'Atlantique Nord (AGARD/OTAN) pour effectuer un tour d'horizon complet des techniques psychophysiologiques disponibles, y compris les types de problèmes en recherche aérospatiale auxquels elles sont susceptibles d'application, le raisonnement de base, les procédures d'enregistrement et les stratégies analytiques spécifiques à chaque mesure. Le texte donne des exemples de travaux de recherche orientés-opérations où les mesures psychophysiologiques en sont parties intégrantes. Bien que la véritable mise en oeuvre des techniques psychophysiologiques demande une expérience et une formation bien plus grandes que ce qui pourrait être obtenu par la simple lecture de ce rapport consultatif, les informations qui y sont présentées devraient servir de point de départ aux chercheurs intéressés par l'emploi des mesures physiologiques. En outre, une liste des noms et des affiliations des scientifiques impliqués dans l'étude de différents types de phénomènes psychophysiologiques dans les pays membres de l'OTAN a été établie. Cette liste offre aux psychophysiologues, débutants comme chevronnés, une source de références sur laquelle ils peuvent compter lorsqu'il s'agit d'appliquer de nouvelles procédures ou de réviser les anciennes.

Ce rapport est organisé en quatre chapitres suivis de neuf annexes. Le premier chapitre présente un aperçu du raisonnement de l'emploi de techniques psychophysiologiques, ainsi qu'une discussion des avantages et inconvénients de ces techniques. Le deuxième chapitre fournit des informations sur la mise en oeuvre de mesures psychophysiologiques pour l'étude de problèmes opérationnels tels que les problèmes résultant de la perturbation des rythmes circadiens, des éléments stressants ambiants et de la fatigue. Le troisième chapitre donne la description des attributs de base de chacune des mesures psychophysiologiques choisies pour analyse lors de l'étude des problèmes mentionnés au chapitre 2. Le quatrième chapitre commence par la discussion des considérations particulières dont il faut tenir compte si l'on veut employer des techniques psychophysiologiques et conclut par des exemples illustrés de projets de recherche récents où ces techniques ont joué un rôle décisif. Les annexes décrivent en détail la méthodologie préconisée pour la collecte et l'analyse de chacune des mesures psychophysiologiques décrites dans le corpus du rapport. Chaque annexe est en grande partie indépendante, quoiqu'il existe un certain nombre de points communs entre les différentes procédures exposées. Dans le cas où, suite à la lecture de la discussion d'une mesure quelconque, le lecteur souhaiterait obtenir des informations complémentaires, il doit consulter la liste des psychophysiologues afin d'identifier un expert ayant des connaissances concernant une technique psychophysiologique ou un domaine de recherche particulier.

Il existe, bien sûr, une littérature considérable sur chacune des techniques psychophysiologiques dont il est question ici, et ce rapport ne prétend pas fournir une évaluation exhaustive de chaque mesure.

Nous avons préféré concentrer nos efforts sur les défis uniques représentés par l'application de ces techniques en environnement aérospatial opérationnel. En particulier pour le psychophysiologue novice, ce guide devrait permettre d'alléger en partie le sentiment de frustration souvent éprouvé par ceux qui doivent faire la transition entre le laboratoire de recherche de base et les réalités du monde opérationnel.

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CHAPTER 1
THEORETICAL FRAMEWORK

An earlier AGARDograph outlined a standardized approach to the performance testing of human subjects who were under the influence of various stressors (AGARD, 1989), and suggested there are two basic purposes for performance tests: the first being to evaluate the impact of stressors on subjects, and the second being to determine an individual's information processing capabilities. To accomplish both of these objectives, the strategy stated in that report was to select a battery of performance tests which measured specific aspects of information processing based upon subjects' responses to various test items. Then, depending upon the test results, inferences are made about the probable effects of a given stressor on aspects of operational performance. This approach corresponds to the objective of human performance theory, which is to explore "lawful relations between task variables and performance" (AGARD, 1989, p. 2), and to indirectly assess the effects of environmental/experimental manipulations via a performance-testing strategy.

The present AGARD Advisory Report is intended to outline another approach to assessing human subjects in operational contexts. However, rather than relying upon a performance-based strategy, the investigation of physiological variables within a psychophysiological framework is proposed. The psychophysiological approach, also useful in estimating the impact of environmental/experimental manipulations on performance, is defined in terms which are different from those of Human Performance Theory. Psychophysiology has been defined as "the study of psychological processes in the intact organism as a whole by means of unobtrusively measured physiological processes" (Furedy, 1983). Thus, a psychophysiological strategy allows the study of the impact of stressors on a different level than is possible with a cognitive-performance strategy. The psychophysiologist is able to contribute some understanding about the underlying physiological changes accompanying the behavioral changes which are studied in a performance-based approach. For instance, where behavioral testing can discern that fatigue results in slower responding to test items, the psychophysiological approach can demonstrate that the slower responses are due to a reduction in central nervous system arousal or activation as opposed to a motor-response or muscular impairment.

Psychophysiology challenges the sufficiency of verbal reports, rejects reductionism as the way to understand human nature, and questions the assumption that behavioral measures are the optimally sensitive measures of underlying processes (Cacioppo and Tassinary, 1990). Psychophysiology, the integration of psychology and physiology, uses non-invasive procedures to understand psychological events by examining the concurrent activity of the brain, muscles, heart, etc., and seeks to understand the relevance of physiological events by exploring them in the psychological realm (Coles, Donchin and Porges, 1986).

The advantages of psychophysiological assessments do not simply rest in their ability to explore the causes of a cognitive, emotional, or behavioral effect. Through psychophysiological techniques, it is often possible to gain information which is not accessible through standard behavioral techniques. For example: 1) psychophysiological assessments are at the core of the detection of deception ("lie detection"), 2) they are useful in clinical applications such as the assessment of hearing and vision deficits in disabled/impaired children and the diagnosis of neurological and psychiatric problems in patient populations, and 3) psychophysiological strategies are extremely relevant in an array of research applications, from studying practical problems such as vigilance decrements in demanding work settings to evaluating job demands in industrial personnel (Andreassi, 1989).

Psychophysiology may be used to evaluate the psychological fitness of operators, investigating whether the body is in an optimal state to perform a particular task. When someone is not fit for a mission, it doesn't necessarily mean that he or she is ill. Rather, their energetic state may not be optimal because activation is too low due to sleep loss or fatigue, stress, negative emotions, or some pharmacological substance. Physiological information about a person's readiness to perform can be combined with other information about that person's general well being and their actual job performance to better predict future operational capacity.

Besides assessing the body's capacity for task performance in terms of physiological activation or arousal, it is desirable to determine whether there are difficulties meeting the requirements of the mission, whether cooperation with crew members is occurring, and whether the job is being efficiently accomplished. In order to make an accurate assessment of performance readiness, psychophysiological measures should be related to other information, such as performance efficiency, subjective ratings for mood and mental load, and ratings and observations of group dynamics. To evaluate the state of the body, one could also ask, "How do you feel?", or "How difficult do you find this mission?". Of course, one should ask these questions, but physiological measures may provide additional information that is more objective. This is because an operator may not realize that his/her state is not optimal or may not want to convey this because it might result in negative judgments of instructors, crew members, or control center personnel. Therefore, objective measures should be collected to accurately estimate the current performance capacity of an individual.

Objective measures of the mental demands placed on operators by their work situation are also needed. Mental workload assessment is becoming increasingly important as the systems people are asked to operate become more complex. Human capacity is sometimes the limiting factor in system performance which requires that we are able to assess this crucial component of the overall system. This evaluation is usually made with various subjective and, to a lesser extent, performance metrics. These approaches have problems of operator bias, memory limitations and accuracy. Psychophysiological measures can provide a more objective view of operator state and capacity and should be used in conjunction with the other measures. Psychophysiological measures are able to provide information about several different components of human cognition and performance. They are continuously available so that moment-to-moment assessment is possible and their collection does not intrude onto the operators' primary task.

The decision about whether psychophysiological measures can or should be collected within a specific context should be based on a thorough comparison of these measures with subjective, performance, and secondary task measures. There are both advantages and disadvantages to the psychophysiological approach which should be considered.

The advantages which make the psychophysiological approach attractive are (see Kramer, 1991):

1. Most physiological measures are unobtrusive. They only require the attachment of sensors to the body, which usually is quite acceptable for the operator.
2. These procedures have practically no interference with the execution of tasks because the operator is not required to attend to any distracting secondary demands.
3. The measurements often can be obtained continuously and do not require overt responses from the operator.
4. The findings are regarded as objective since they do not rely on operator judgments which may or may not be accurate.
5. The information obtained is multi-dimensional when measures are obtained from different response systems (i.e. when brain and respiratory measures are collected in addition to heart rate).
6. Comparisons of multitask environments and of complex situations, in general, are more feasible than is often the case with performance measures. This means that operational systems can be evaluated with regard to their demands on human resources and effort.
7. Individual differences can be used to advantage since the unique response patterns of an individual can be determined. This is especially true in applied settings since operators at their jobs daily provide many opportunities to collect baseline data.

Although there are many attractive reasons to employ psychophysiological measures, there are also problems which should be considered. These problems are not all unique to psychophysiological measures, but are shared with performance and subjective measures as well. The problems are:

1. Although the cost of recording systems has decreased dramatically, specialized equipment, which is often expensive, is needed especially for flight conditions.
2. No standardized methods and techniques are available with regard to equipment, sensors, analyses, and recording procedures, although this Advisory Report will address several of these issues.
3. Considerable expertise is required to properly measure, analyze, and interpret most psychophysiological data, which minimizes it's use by some operational personnel. However, this problem should be reduced by reports such as the present one which provides basic useable information within reach of both research and operational personnel.
4. The signal-to-noise ratio is rather poor for some measures so one may experience problems recording valid data in operational contexts (advances in technology have alleviated many of the problems in this regard, but users still must be careful to select measures which are as robust as possible for field application).
5. The variability between and within subjects is also relatively high so that baseline measures must be collected on each individual. (This, however, does provide the opportunity to take advantage of each person's unique response profile).
6. Most measures of one response system are sensitive to interference from other response systems (muscle activity and eye movements interfere with the electroencephalogram, or movement, speech, and body position interfere with cardiovascular measures).
7. Most of the measures are sensitive to more than one factor. For example, most measures are not only affected by workload and effort, but also by stress, emotions, physical environment, physical exercise, and drugs. This is, however, not always a problem due to the fact that much applied research is designed to determine whether a specific intervention leads to any problems or improvements rather than to determine the exact factor(s) which were involved in the observed changes. However, relevant concomitant variables to measure confounding factors, for example temperature and physical activity, should be recorded whenever possible to assist in correct interpretation of the physiological data.
8. The interpretation of findings still poses a problem in some situations, because a generally agreed upon theoretical framework is not yet available. The ultimate goal is the evaluation of human performance or the understanding of the functioning of a particular operator. For the prediction and understanding of human behavior in response to system and group demands, it is necessary to have a strong conceptual link between physiological and psychological factors. However, the absence of a clear theoretical framework, while presenting some interpretive problems, does not render a measure or set of measures entirely useless. For instance, researchers continue to gain important information from sleep polygraphy (electroencephalographic, electromygraphic, and electro-oculographic) data in that they may conclude an intervention adversely affects sleep quality, but there remains much uncertainty about the precise mechanisms through which sleep impacts performance (although it obviously does have an impact).

Despite these possible difficulties, however, there are many examples of collecting psychophysiological data to assist with the evaluation of operationally relevant stressors. A few are: the study of 1) pharmacological stressors on the nervous system and performance of pilots (Caldwell, Stephens and Carter, 1992); 2) the prediction of error rates using EEGs in a sonar auditory target detection task (Makeig and

Inlow, 1993); 3) the impact of circadian disruptions on EEGs and performance of aircrews (Comperatore and Caldwell, 1992); 4) the effects of heat stress on sleep quality of helicopter pilots (Caldwell, Thornton, Pearson and Bradley, 1992); 5) the relationship between EEG and vigilance during prolonged performance (Belyavin and Wright, 1987); 6) the correlations between brain activity and pilot performance (Sterman et al., 1987); and 7) the relationships among heart rate, eyeblinks, EEG, and pilot workload in actual versus simulated flight (Wilson et al., 1987), just to name a few. Several of these studies attest to the fact that psychophysiological measures are obtainable even while the primary task is being performed (as opposed to the administration of secondary tests which may detract from relevant, primary task performance). Additionally, the results from these investigations highlight the fact that physiological measures combined with behavioral measures often offer a more comprehensive assessment of the impact of environmental/experimental manipulations in aerospace research than would be possible using either set of measures in isolation.

It is clear that the collection of physiological measures can form an essential part of a monitoring system that can be used to continuously evaluate the state of an operator for determining psychological fitness and the effects of mental load and stress. For example:

1. The evaluation of the psychological fitness of an operator is accomplished by detecting deviant or abnormal physiological signals that indicate a less than optimal state, or tendencies toward a disrupted state indicating stress or impairment from environmental or chemical stressors. This information may be used to optimize performance, to prevent reduced well-being or health, or to prevent accidents. The prevention of reduced well-being is primarily oriented to the individual operator. This has implications not only for the choice of monitoring methods, but also for the countermeasures employed. They may consist of a temporary reduction in workload, timely cancellation or delay of a mission, or of social support by colleagues in the work environment or in the control center.

2. Psychophysiological measures may also be used as part of a system to examine mental load and stress as induced by work demands of individual tasks or the interference between tasks in multi-task performance. Psychophysiological measures may provide an index for the "costs" involved in executing tasks. On the basis of this information, system configuration, work design, work/rest schedules, and task allocation may be improved. These measures can also be used to examine the effects of adverse environments and of environmental stressors (e.g., sleep loss, G-load).

It is important in this context to consider collecting multiple measures whenever possible due to the fact that there is large variance among individuals in terms of how they respond to the environment and/or internal events. For example, some people may respond with reactive changes in the cardiovascular system while others may respond primarily with changes in the central nervous system. Due to the complexity of human behavior and the great variability in response patterns, a single physiological measure may not have the power to reveal an effect whereas, with multivariate analysis techniques, a combination of different physiological measures and performance indices can be successfully employed. For example, a combination of multiple physiological measures, performance variables, and subjective measures has been used to classify different types of flight segments with regard to operator workload (Wilson and Fisher, 1991).

Of course, the specific measures chosen for use in an investigation must be carefully considered at the outset. For example, if the researcher is concerned about the effects of an intervention on subjects' abilities to acquire data from a sensory standpoint, sensory evoked potentials (auditory and visual) and/or eye movement data may be important. If the concern is over how subjects process information, electroencephalographic data or cortical evoked potentials are the most valuable. If stressful physiological exertion is expected and safety monitoring is a concern, then measures of heart rate and core body temperature should be considered paramount. Ultimately, any or all of these measures can be collected as the situation demands, but the specific choices should be made in advance dependent on the goals of the research.

On the basis of available data from laboratory and field studies it is obvious that psychophysiological measures will provide much useful information about human performance. Recent technological advances have provided the hardware and necessary procedures for collecting physiological data from ambulatory subjects at their work. This makes the recording of psychophysiological data available to the non-expert who wants to know more about human performance at the work station, including simulated and actual flight. The purpose of this AGARD Advisory Report is to provide basic background information about psychophysiological measures and application areas so that a wide range of researchers and applied workers can evaluate the utility of these measures for their specific applications. This report is not meant to be the only source of information, but rather is intended to provide a summary of information and provide references for further investigation. It is the opinion of the members of AGARD Working Group 19, "Psychophysiological Assessment Measures", that psychophysiological measures can provide valuable information about human performance in applied aerospace settings and that these measures should be considered for use along with subjective and performance measures.

CHAPTER 2
APPLICATION AREAS

Introduction

Numerous problems affecting the performance of military personnel and workers in operational and training settings have been studied using psychophysiological measures. The table below offers an overview of specific application areas and the types of physiological data which have been collected to resolve various research and/or other issues. The areas presented here have been chosen because they are of central importance in aviation research, but there are others which can be studied using the same psychophysiological techniques. While there is some overlap among the areas discussed here, they are treated somewhat separately because of the importance of each to an aviation context. The reader should take into consideration that many of these applications are interrelated and the list presented here is by no means exhaustive.

The table presented below provides a quick overview of the types of psychophysiological measures which have proven useful in studying problems within each application area. Although activity measures (ACT) are not psychophysiological, they are included since activity monitoring is often done in conjunction with the collection of psychophysiological measures.

In some cases it has proven useful to simultaneously collect many different measures including electroencephalographic (EEG), electro-oculographic (EOG), electromyographic (EMG), cardiovascular (CARDIO), blood/urine (FLUIDS), temperature (TEMP), activity (ACT), and respiration (RESP) measures, whereas in other cases only a small subset of these measures are typically used.

Application Areas by Measure

Application Area	ACT	EEG	EOG	FLUIDS	CARDIO	EMG	RESP	TEMP
Circadian Rhythms[1]	x			x				x
Drug Effects	x	x	x	x	x	x	x	x
Environmental Factors[2]	x	x	x	x	x	x	x	x
Fatigue	x	x	x	x	x	x	x	x
Mental Load		x	x	x	x		x	x
Psychological Stress				x	x		x	x
Sleep	x	x	x	x	x	x	x	x
Vigilance/alterness	x	x	x		x			x

[1] The circadian rhythms category includes studies of:
1) Work schedules
2) Jet lag

[2] Environmental factors includes studies of:
1) Noise/vibration
2) G forces
3) Temperature and humidity
4) Hypoxia
5) Pressure
6) Light (intensity and color)

Some problems lend themselves to study using a variety of psychophysiological techniques because of implementation and theoretical considerations. Other problems remain more amenable to evaluation using behavioral or cognitive measures (i.e. tests, surveys, etc.). A brief overview of several common operational application areas follows to provide representative examples of how psychophysiological measures have been employed in the past and, hopefully, to suggest methods appropriate for future research.

Circadian Rhythms

Dynamics of circadian rhythms and sleep are governed by endogenous regulation systems for which mathematical models exist (Borbély and Achermann, 1992). The concept of a computer model for circadian dynamics is shown in figure 1 (Gundel and Spencer, 1992). This model assists in explaining the relevance of circadian variations in psychophysiological variables for aeromedical investigations.

The core of the model is a circadian pacemaker. The pacemaker generates and synchronizes the observed rhythms, such as rhythms in body temperature and performance, and is itself subject to external forces or zeitgebers in the form of behavioral and physical cycles. The behavioral cycles, of which the most important may be the rest-activity cycle, are themselves modulated by the social and working environment, or they may be more rigidly constrained by the conditions of an experiment. The physical cycles, among which the light-dark (L/D) cycle seems to be by far the most important (Wever et al., 1983; Czeisler et al., 1989), can also modulate the rest-activity cycle. On the other hand, the effectiveness of the L/D cycle may be determined to some extent by the pattern of rest and activity.

The broken lines in figure 1 correspond to two factors that are not represented in the mathematical formulation of the model. These are the masking of overt rhythms by the zeitgebers and the feedback from the pacemaker to the rest-activity cycle.

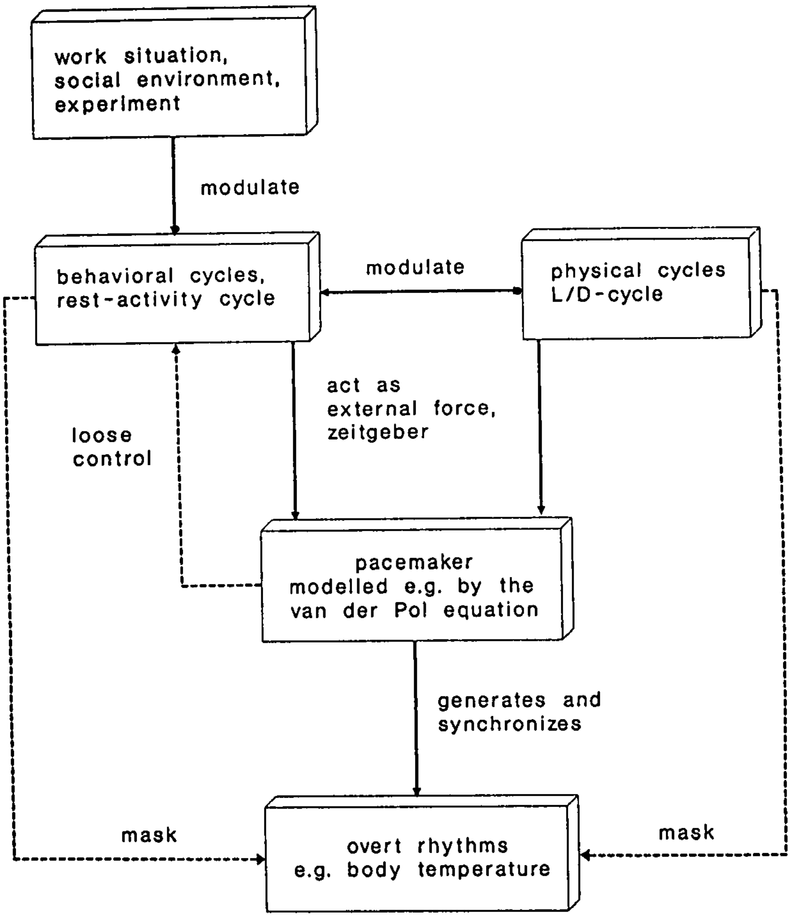

Figure 1. Conceptual diagram of a model for circadian dynamics in the situation of transmeridian travel and shift work.

Part of the daily alterations of human performance (performance in a very broad sense) is determined by the endogenous circadian dynamics. Timing by the body clock results in higher performance during daytime than at night. Changes in the driving forces of the endogenous dynamics will change the daily profile of performance.

A typical situation in which circadian rhythms become important occurs when the physical L/D cycle is shifted relative to the body clock as with transmeridian travel. The results of this shift are generally known as jet lag (Wegmann et al., 1986; Gundel and Wegmann, 1989). In shift working people, frequently a shift of the perceived L/D cycle and the behavioral rest-activity cycle against the endogenous clock results in detrimental effects for performance that are similar to those after transmeridian flights (Minors et al. 1986). Also patterns of irregular work and rest are accompanied by a desynchronization between the body clock and professional demands.

However, circadian dynamics is not the only factor which determines performance during waking time. A subject's sleep history, in particular the amount of sleep the subject receives preceding the performance period is also of considerable importance. The circadian variation of performance is superimposed by a time-since-sleep component that is modulated by various aspects of sleep timing, sleep quantity, and sleep quality (Dijk et al., 1992).

Among the measures available to assess circadian dynamics, the most important are body temperature (Wever, 1979; Strogatz, 1986), melatonin assays (Wever, 1989; Samel et al., 1991; Lewy et al., 1992) and cortisol assays (Weitzman et al., 1981). Each of these measures can be used to determine the circadian phase. However, often a combination of these measures is preferred. The highest time resolution can be achieved by assessing plasma melatonin, but all three parameters show clear circadian variations that are driven by the same pacemaker.

All three parameters have been shown to reliably measure circadian rhythms. The daily profile of melatonin concentration in plasma is reliable to the extent that it has been compared to a fingerprint. The dim light melatonin onset (DLMO), i.e. the evening rise in melatonin production, is taken as a circadian phase marker, and the time of the DLMO varies only slightly from day to day (Lewy et al. 1992). The circadian variation of the excretion rate of the main metabolite of melatonin, melatonin sulphate, is also reliable (Wever 1989; Samel et al. 1991). The circadian phase can be deduced from a sinusoidal fit to the data; however, the time resolution is inferior to that of DLMO. Saliva cortisol, as does cortisol in plasma, shows a stable circadian rhythm that, however, is superimposed by a component related to the rest-activity cycle (Weitzman et al. 1981). Core body temperature is susceptible to a similar daily variation affected by activity--referred to in chronobiological terms as "masking" (Minors and Waterhouse, 1989)--but, it is still the parameter that is most often used in studies of circadian rhythms and sleep. The circadian phase is frequently obtained from an estimate of the time when the daily temperature curve reaches its minimum. This time can be established via the use of regression procedures (Brown and Czeisler, 1992).

Body temperature, which can be measured continuously, shows its trough (the circadian marker) in the early morning during sleep. Conversely, cortisol rhythms, which can be determined from saliva, blood, or urine samples, reach the circadian maximum in the morning. The circadian marker in the melatonin rhythm, which can be determined via blood samples, is its evening increase under dim light (the dim light melatonin onset or DLMO). A concurrent change in the metabolite melatonin sulphate can be obtained less invasively from urine samples.

Drug Effects

The effects of a variety of drugs have been determined using such psychophysiological measures as heart rate, blood pressure, temperature, eye movements, and evoked and spontaneous electrical activity of the brain. Also, plasma, saliva, and/or urine concentrations of certain hormones or neurotransmitters are often assessed to determine the precise effects of pharmacological substances. Representative examples of such investigations are numerous, and only a few will be cited here to show the relevance of psychophysiological measures in determining drug effects.

Within a military aviation context, an issue of frequent concern is how to maintain alertness in personnel despite extended work periods and/or sleep deprivation. One solution is to administer stimulants such as dextroamphetamine, and research has employed an array of psychophysiological assessments to study the feasibility of this alternative. The results have shown both CNS and peripheral effects of these drugs (Weiner, 1980). Oral amphetamine elevates blood pressure (systolic and diastolic), but does not increase heart rate or respiration. The central nervous system (CNS) is stimulated as might be expected from drugs which increase wakefulness, alertness, initiative, and concentration, elevate mood and improve task performance while decreasing fatigue. Amphetamines are known to restore decrements due to sleep loss especially in vigilance tasks requiring sustained attention. Amphetamines alter sleep EEG by substantially reducing the typical amount of rapid eye movement (REM) sleep, and they alter the waking EEG by increasing desynchronous activity and producing a shift toward higher frequencies. Stimulants including methylphenidate can shorten stimulus evaluation processes (Fitzpatrick et al., 1988) as indicated by evoked potential studies. Research is currently underway on newer psychostimulants such as modafinil which appear to have many of the positive effects of amphetamines without some of the negative side effects. Lyons and French (1991) summarized several modafinil studies which indicate that the drug reduces EEG indications of fatigue, improves cognitive performance and mood, and sustains alertness.

Studies of other drugs, such as the benzodiazepines do not always have such a direct military application although some of the short-acting ones (i.e. triazolam and temazepam) have proven their utility to promote sleep in otherwise problematic environments (Caldwell, Comperatore and Shanahan, 1992). Hypnotics that improve sleep but are free of sedative effects upon awakening have been studied using sleep electroencephalography and measures of performance (Nicholson, 1983; Nicholson, Roth and Stone, 1985). In addition, other investigations of benzodiazepines have shown that the characteristics of eye movements including peak velocity, peak acceleration, peak deceleration, and saccade accuracy were altered in a dose dependent fashion after administration of midazolam, and the changes were restored after administration of flumazenil (Ball et al. 1991). These results are consistent with earlier studies of the effects of diazepam, where Rothenberg and Selkoe (1981) found increases in saccade duration and decreases in saccade velocity after 10 mg diazepam, and Stern, Bremer, and McClure (1974) reported decreased saccade velocity with increased fixation pauses. These benzodiazepine findings are in some respects similar to results with alcohol (Lehtinen et al., 1979) and methadone (Rothenberg et al., 1980).

Caldwell, Comperatore, and Shanahan (1992) reviewed the sleep promoting utility of the short acting benzodiazepines temazepam and triazolam, with a primary focus on measures of sleep quality. Temazepam has been shown to improve sleep maintenance throughout the night without interfering with normal sleep architecture as measured by sleep polygraphy (EEG, electromyogram, and electrooculogram). However, the effectiveness of this drug in reducing sleep onset depends on the absorption characteristics of the formulation (the hard gelatin capsule is not known for effectiveness in reducing sleep onset). Triazolam has proven useful in improving both sleep onset and continuity, but it tends to alter the amount of stage 2 sleep and the latency to the first REM period after only short term use. In addition, there have been reports of adverse effects associated with triazolam use, but there is considerable debate about the validity of such concerns (Rothschild, 1992).

Other drugs which have been assessed with EEG based measures are quite numerous. Vollmer et al. (1983), in their study of the sedative effects produced by ketotifen, reported that the dominant alpha (8-12

Hz) frequency was slowed, the amount of power associated with fast alpha activity was reduced, and the relative amount of slower theta activity was elevated as a function of even mild drug induced sedation. Caldwell et al. (1992) and Pickworth et al. (1990) reported significant increases in delta, tendencies toward increases in theta, and marked reductions in alpha activity as a consequence of atropine administration (a chemical warfare antidote). These effects were present at 2 and 8 hours postdose and were accompanied by behavioral evidence, including self-reports, of increased sedation. Sittig, Badian, Rupp, and Taeuber (1982) observed somewhat similar effects on slow-wave EEG with 2 benzodiazepines, diazepam (10 and 20 mg) and clobazam (20 and 40 mg). Both diazepam and clobazam produced an increase in theta and slow beta activity, with the most pronounced effects associated with diazepam. The impact of diazepam was also observed on correct responses to a multiple-choice reaction time test where there was a significant increase in response times.

A study on the effects of antihistamines (Goldstein et al., 1968) further supported these findings regarding the effects of sedative drugs on EEG. Goldstein reported an increase in delta and theta activity, a decrease in alpha, and a slight increase in beta as a function of diphenhydramine administration. This report corroborates earlier findings by Nowell, Chinn, and Haberer (1955) that diphenhydramine was among the most sedating antihistamines of 33 tested. Nowell et al. found that diphenhydramine administration produced significant drowsiness as defined by an increase of EEG activity below 7.5 Hz accompanied by some elevations in beta levels. Fink and Irwin (1979) also found an increase in delta activity and a decrease in alpha under diphenhydramine; however, they also saw a reduction (rather than an elevation) of theta. Stephens et al. (1992) reported EEG changes that consisted of reductions in alpha activity as a function of diphenhydramine administration, but for methodological reasons related to a narrower frequency range for beta activity, Stephens was unable to corroborate the earlier findings regarding slight increases in fast EEG. Stephens et al. (1992) did, however, note that antihistamine administration did not produce problems with flight performance of aviators in a helicopter simulator.

Studies have been carried out to investigate central effects of analgesics which may lead to sedation, including aspirin, paracetomol, codeine phosphate, meptazinol, and pentazocine (Bradley and Nicholson, 1986; Bradley and Nicholson, 1987). Central effects were assessed using tests of visual acuity, visuo-motor coordination, critical flicker fusion and psychomotor performance.

The central effects of antihypertensive drugs, including atenolol, propranolol, captopril, and nifedipine have been investigated using the EEG, body sway, and critical flicker fusion together with a range of performance tests (Nicholson et al, 1988; Nicholson et al, 1990; McDevitt et al, 1991).

In terms of more general drug effects on the central nervous system, it is known that phenothiazines produce dose related increases in alpha, theta, and delta activity; barbiturates produce elevations in frontal, central, and/or more generalized beta as well as increases in theta and delta; benzodiazepines are associated with increased beta activity; and amphetamines cause decreases in slow EEG activity with increases in faster activity (Cadwell Laboratories, 1987). There are characteristic patterns for other classes of drugs as well, but such a discussion is beyond the scope of this Advisory Report.

In summary, it is clear that several psychophysiological measures are useful for studying the effects of drugs, and the choice of measures depends on the problem of interest. Examinations of cardiovascular measures have often been used in investigations of tricyclic antidepressants because of the concern over drug-induced cardiac failures. Cardiovascular activity and/or cognitive measures are frequently collected in studies of nicotine, caffeine, and amphetamine because of the activating properties of these substances. Electroencephalographic measures are among the most sensitive for detecting the presence of central effects, in particular those of reduced arousal associated with sedative compounds as well as elevated arousal associated with stimulants.

Environmental Factors

The aviation environment presents a variety of factors which act as stressors to produce adverse physiological and behavioral consequences. These factors, including acceleration, vibration, heat and noise, usually act synergistically and their combination provides a hostile environment that requires adaptation, training, and protection to enable adequate levels of human performance to be preserved.

Acceleration. Physiological effects are produced by sustained distortion of body organs and changes in flow and distribution of blood and body fluids. The effects on behavior are due to decreased blood flow in the brain and retina, produced by disturbances in pressure in the cardiovascular system.

In an unprotected relaxed individual, G-induced loss of consciousness (G-LOC) occurs between +5 and +6 Gz depending on rate of onset of G. At lower rates of G, there is decreased visual acuity and loss of peripheral vision known as grey-out. At higher levels of acceleration visual black-out occurs. Disturbance of vision precedes impaired hearing and mental activity, with normal conversation intelligible until consciousness is lost.

Information on the incidence of G-LOC is provided by subjective reports and questionnaires, although more objective techniques including physiological monitoring may be considered to be more useful (McCloskey, et al., 1992). Changes in the EEG with acceleration are evident (Lewis et al, 1988), with the appearance of slow waves in the delta range accompanying loss of consciousness. Increased alpha and beta activity occur during visual grey-out, while alpha disappears with black-out. Acceleration is accompanied by electromyographic changes associated with loss of facial tone and jerking of the neck. The electrooculogram shows slow rolling activity and DC-level shifts as loss of consciousness occurs. Mobility is affected by acceleration, with gross movement of limbs and trunk impaired to a greater degree than fine control. Cardiac arrhythmias and increased heart rate occur during and after acceleration, and there is a specific endocrine response to G with increases in serum cortisol and catecholamine levels.

Heat. Air temperature, humidity and air movement combine to produce the effects of heat. The initial physiological response to heating is vasodilation in the skin, followed by active sweating. A hormonal response occurs, with an increase in aldosterone secretion by the adrenal cortex to aid conservation of sodium by the kidneys.

Heart rate is increased and generalized feelings of lethargy occur, and performance may be adversely affected depending on skin and core temperature. Heating alters sleep patterns, with passive body heating before sleep producing increasing EEG slow wave activity and reducing the amount of REM sleep (Horne and Reid, 1985; Bunnell et al, 1988) while elevated temperature during sleep increases awake activity and incidence of sleep disturbances (Karacan et al, 1978; Di Nisi et al, 1989).

Hypoxia. Hypoxia impairs performance in a wide range of tasks, and the decrement is correlated with the degree of hypoxia. The impairment varies both between and within individuals. Some proportion of this variation may be due to differences in the respiratory responses to hypoxia causing temporal and individual differences in the tensions of oxygen and carbon dioxide in arterial blood. Hypercapnia (pCO_2 levels below normal values) induced by low arterial oxygen tension affects mental performance by reducing still further cerebral tissue oxygen tension, as a consequence of the cerebral vasoconstriction, and by increasing the Ph of cerebral tissue.

Simple reaction time is not usually affected below 10,000 ft while choice reaction time is. Tasks requiring complex hand-eye coordination such as instrument flying are usually unaffected when they have been well learned. The decrement in pursuit-motor tasks is minimal until 12,000 ft. but becomes severe above 16,000 ft. Psychomotor performance is also compromised by impairment of muscular coordination and the development of fine hand tremors at altitudes above 16,000 ft.

Overlearned psychomotor tasks are unaffected up to at least 10,000 ft, as are both long-term and short- term memory, arithmetic, and conceptual reasoning. Above 10,000 ft., performance at coding and reasoning tasks decrease with increasing altitude. The completion time of simple coding tasks is increased by 10 - 15% at 15,000 ft. and by as much as 40-50% at 18,000 ft. The degree of performance impairment at high altitude varies with task complexity and difficulty.

Subjects breathing air at 8,000 ft take significantly longer to achieve optimum performance at novel tasks. Hypoxia at this altitude increases the reaction times of initial responses to complex choice reaction tasks compared with responses at ground level.

Hypoxia leads to pronounced changes in cerebral oxygen metabolism and cerebral blood flow. Effects on the EEG include reduced alpha and beta activity, together with increased slow wave activity in the delta and theta frequency bands (Kraaier, Van Huffelen and Wieneke, 1988). Stimulus evaluation processes are slowed by hypoxia (Fowler and Kelso, 1992) as indicated by changes in P300 and N200 latency. Visual perception and processing are particularly sensitive to the effects of hypoxia (Fowler, Banner and Pogue, 1993). Hypoxia has been reported to result in dizziness, headaches, visual disturbances, and subjective awareness of reduced performance. Hormonal responses to hypoxia include decreased testosterone and cortisol levels, while prolactin seems to be unaffected (Vaernes et al, 1983).

Motion Sickness. Most people have experienced motion sickness at one time or another and are aware of its effects on performance. Illness of any kind can interfere with one's cognitive activity and have deleterious effects on performance. At the extreme, crew members can become incapacitated and not be able to perform their duties. The effects can vary from suffering in silence with impaired performance to vomiting, to becoming totally unable to perform ones duties. Space sickness is also a problem experienced by up to 50% of the crew members (Benson, 1988). Simulator sickness is becoming more of a problem with increased realism of current and future simulators and some investigators have reported motion sickness symptoms to virtual reality exposure (Kennedy, Hettinger and Lilienthal, 1990).

Changes in several physiological measures are seen prior to and during motion sickness (Cowings, et al., 1986). These include cardiac, respiration, skin conductance and skin pallor measures. Electrogastrograms have been used to study motion sickness (Stern, Koch and Vasey, 1990). Chelan et al (1990) have reported the appearance of slow frequency activity in the EEG just prior to vomiting by subjects in a rotating chair. They further linked this EEG activity to a neurological disorder and reported success in pretreating the motion sickness with an anticonvulsant drug, phenytoin. Biofeedback of physiological signals has been successfully used to treat motion sickness in susceptible aviators (Cowings, 1990).

Noise. Excessive noise both in the aircraft cockpit and arising from environmental sources such as road traffic and aircraft has pervasive effects on behavior in addition to causing temporary or permanent damage to hearing. In addition to specific effects on performance and physiological variables, generalized fatigue and psychological effects such as irritation and increased stress occur. Communications may be degraded, including intelligibility of speech and other auditory signals, effectively increasing workload through the need for unnecessary repetition of information and increased attention requirements.

Although it is generally agreed that damage to hearing does not occur at noise exposures below 75-80 Db(A), adverse effects of noise on performance occur at well below this level. Sudden or intermittent noise is more disruptive than continuous noise, and high frequencies affect performance more than lower frequency components.

The effects of noise are commonly determined by subjective assessments and by objective techniques such as performance measures either in the laboratory or in occupational settings. Noise is particularly disruptive to tasks requiring multiple activities, attention sharing, divided attention, and memory (Abel, 1990), and tends to increase errors and performance variability. Tasks that involve auditory stimuli are generally more sensitive to the effects of noise.

Noise is associated with physiological changes including increased heart rate, peripheral vasomotor effects, and modified spectral content of the EEG (suggesting increased arousal). Disturbance of the normal patterns of sleep occurs with exposure to noise, with increased awakenings and changes in the cyclic nature of sleep (Griefahn, 1986; Fruhstofer, Pritsch and Fruhstorfer, 1988; Thiessen, 1988; Stevenson and McKellar, 1989; Bach et al, 1991; Nicolas et al, 1993).

Pressure. Exposure to a high pressure environment can cause a range of neurological symptoms including nausea, fatigue, cognitive decrements, and tremor. There is considerable inter-individual variability in susceptibility to the effects of hyperbaric conditions. The EEG during saturation diving and simulated pressure in hyperbaric chambers shows a characteristic increase in slow wave activity in the theta band (Dolmierski et al, 1988; Ozawa and Tatsuno, 1989; Okuda, Matsuoka and Mohri, 1988; Lorenz, Lorenz and Heineke, 1992) and there is evidence of decreased alertness and impaired performance.

Vibration. Exposure to high levels of vibration exerts a wide array of effects on human operators. The effects of whole body vibration are typically assessed in terms of the effects on operator comfort, performance, and health and safety (ISO 2631, 1985). As vibration levels increase, and/or as the duration of exposure at a specific vibration level increases, it is thought that the operator passes through these three boundaries.

The commercial passenger transport industry is most concerned with the comfort boundary. Here, for example, the automobile industry views vibration as a system input/output problem where the input begins with an assessment of the terrain surface roughness and is filtered through the tires, suspension, vehicle frame, vehicle body, and the seating system. System vibration output is now considered an input to the operator and affects the operator's perception of overall vehicle comfort. The primary measure of passenger comfort is subjective assessments. These assessments are correlated with different aspects of vehicle vibration signatures and are used to tune the system to move or reduce the regions where the signature is considered uncomfortable. Similar approaches are used, for example, in seat design for the airline industry.

Studies of the effects of whole body vibration in the work place are primarily concerned with the fatigue and decreased proficiency boundary and the exposure limit for the seated operator. System approaches are also used in assessing the sources, attenuators, and amplifiers of whole body vibration. Operator inputs of whole body vibration are made using triaxial accelerometers aligned with the fore/aft (X), lateral (Y), and vertical (Z) axes using a seat pad placed between the seat cushion and the operator's buttocks (SAE J1013). Assessments of the severity of the vibration signature are made using the methods outlined in ISO 2631.

Operators are least tolerant to accelerations in the X and Y axis, and most tolerant of Z axis vibration. However, Z axis vibration is typically an order of magnitude, or more, larger than X or Y axes, and is therefore the axis of most concern.

Whole body vibration affects operator fatigue and performance by acting as an additional stressor to the body. The acute physiological effects of whole-body vibration primarily fall in the areas of muscle response, circulatory function, respiratory function, and visual perception.

Myoelectric changes associated with whole body vibration exposure depend upon the type of the vibration signature. Low frequency sinusoidal vibration (<15 Hz) results in a sinusoidal burst pattern in the surface electromyogram (EMG) recordings that is correlated with the vibration velocity. Random whole body vibration results in a complex burst pattern. Muscle fatigue is manifested by reductions in the EMG median frequency, increases in the low frequency EMG content, and decreases in the high frequency EMG content. Primary muscles involved in this response are the extensor muscles of the back and neck.

Changes in heart rate, stroke volume, and blood pressure associated with vibration are similar to those seen with light muscular activity. Other stressors in the work place can easily mask these small changes. Peripheral vasoconstriction reduces blood flow to the extremities as a result of whole body vibration. Temporary changes in hearing thresholds have been reported.

Respiration is affected by whole body vibration primarily through the effects of body organ resonances. At a resonance of 4-8 Hz organ displacement can cause passive movement of the diaphragm inducing hyperventilation. Oxygen consumption also increases in this range and is attributed to an increase in muscular activity.

Visual perception is primarily affected by the inability to keep an image on the retina for a long enough period of time to perceive the target. The difficulty in fusion is attributed to target motion, whole body motion (4-8 Hz), and ocular resonance (12-25 Hz). Below 4 Hz ocular motion can compensate for target or whole-body displacements.

Vibration also produces a sensory mismatch leading to degraded processing of information and performance. Auditory evoked potentials are affected, with reduced amplitudes and increased latencies (Seidel et al, 1990a, 1990b), and the EEG reflects reduced wakefulness (Landstrom and Lundstrom, 1985).

Fatigue

Fatigue is basically the state of "feeling tired" which results from a lack of rest and is generally considered to be a cumulative entity. Thus, fatigue may be produced from many factors which include sleep deprivation, prolonged physical or mental work, or even the simple requirement to remain at one's duty station for a lengthy period regardless of the amount of work which is actually demanded.

Research into the effects of fatigue reveals that a precise understanding of the construct is somewhat elusive. There is evidence that, in many cases, the performance impact of fatigue is more psychologically or motivationally based rather than being a product of absolute physical or mental limitations. Prolonged work, however, does not necessarily lead to physiological impairments or reductions in work performance, although there is evidence that "fatigued" subjects tend to perform poorly and behave carelessly on the task at hand, and they often fail to attend to minor peripheral details (Holding, 1983). Many investigations have been conducted to examine the fatigue induced changes in the performance of simple and complex tasks, behavioral characteristics, and/or physiological variables. In these studies, the subjects' levels of fatigue have been manipulated in a variety of ways to include depriving people of sleep and/or requiring them to perform a specific task for lengthy periods of time.

The fatigue which results from sleep deprivation has been of interest for many years. Krueger (1989) summarized several of the more salient performance effects of sleep deprivation as: 1) increased mental "lapses" which have an impact on the speed and accuracy of responses, 2) reduced ability to acquire and recall information in complex tasks, 3) changes in brain activity associated with decreased alertness, and 4) an overall slowing of cognitive ability in which task performance declines in conjunction with mood and motivation.

Horne (1978) reviewed the biological/physiological effects of sleep deprivation and provided tabular summaries of the measures which have been used. It has been found that heart rate, oral temperature, respiration, and saccadic eye movement velocity typically decrease as a function of sleep loss. In addition, the alpha frequency of the EEG is often reduced and generally there is a slowing of the EEG. Changes in urinary catecholamines have been observed in some cases, but overall the results are inconclusive.

As for the effects of requiring people to perform under demanding, extended schedules, studies show that cognitive performance tends to decline and this is associated with changes in the EEG (Comperatore et al., 1993). EEG alpha activity is often reduced during prolonged flights, long drives, or extended duty periods. Holding (1983) points out that fatigue often leads to skilled performance becoming more disorganized, with larger deviations being seen as acceptable while lapses in performance increase in frequency. Comperatore et al. (1993) found that cognitive spatial ability was impaired after 48 hours of continuous testing and this was associated with increased slow EEG activity and changes in the morphology of middle latency evoked responses.

Interface Evaluation

Technology has greatly improved the pilot's job, extending the flight domain to all weather conditions, night flight, and other extreme situations. But in spite of great advances in technology, human reliability has remained essentially the same. Approximately 88% of serious accidents in general aviation recently have been attributed to human factors (Amalberti, 1992).

The design of man-machine systems has made such advances in the course of the past ten years that its very basic principles are now questioned. Three main developmental periods can be distinguished (Menu and Amalberti, 1992). The first one corresponds to post-war World War II when ergonomics was centered on working conditions which fostered great progress in making systems compatible with psychosensory capabilities of aircrew and gradually modernized operating instruments. In the second period, ranging from 1980 to 1990, cognitive ergonomics developed with the concept of man-machine interface. During this period, a part of the operator's mental workload was carried out by computers, requiring a thorough cooperation between man and machine. This area involves understanding complex systems and complex human performance, making the implementation of these interfaces and the evaluation of their effectiveness difficult. Traditional assessment methods (performance and subjective) may not be sufficient, especially with regard to evaluation, and it is here that psychophysiological measures may be helpful since they are continuously available and non-intrusive into the operator's task. The third period, 1990-2000, is the era of interactive ergonomics which addresses the various disciplines of cognitive sciences based on the concept of parallel coupling and man-machine cooperation with bilateral exchanges of information.

In order to evaluate constant changes, it is desirable to apply psychophysiological measures to the evaluation of the man-machine interface. Some psychophysiological parameters are a reflection of a good or poor interface between man and machine. Among those commonly used in aviation medicine are the cardiovascular parameters such as heart rate and brain blood flow, hormonal parameters, the electroencephalogram, and the electro-oculogram.

The determination of heart rate by electrocardiographic recording has been common practice in aviation medicine for many years. The first inflight electrical recordings date as far back as 1940 (White, 1940), followed by a number of other investigations (Rowen, 1961; Holden, 1962; and Helvey, 1964). In 1966, Balke studied the EEG by telemetry at distances of more than 75 miles from the aircrew. More recently, other measures have been made by Quandieu et al. (1989) on aircrew flying Mirage 2000 aircraft. Heart rate has been found to exhibit good correlations with the difficulty of the task.

The evaluation of brain blood flow by a transcranial Doppler system mounted on the helmet is another cardiovascular parameter which is used in the laboratory and inflight (Glaister, 1990; Clere et al. 1990). This method shows that there is often a relationship between the reduced velocimetric signal of blood circulation in the middle cerebral artery and the narrowing visual field sometimes associated with loss of consciousness.

Hormonal parameters, determined by blood and urine assays, indicate the status of stress and workload of a subject and therefore reflect the adequacy of the man-machine interface. The secretion of certain hormones, such as catecholamines for example, increases under stress and hypoxic conditions. Cortisol can be assayed in urine (Marchbanks, 1958; Hale, 1968) and in saliva (Warren, 1965; Kirschbaum et al., 1989; Wade and Haegele, 1991).

The analysis of electroencephalographic recordings provides insight not only into the state of vigilance of the aircrew during various flight phases (Coblentz et al., 1990) but also on their mental workload (Hicks, 1990) and on their performance or control of the situation during different flight phases (Sterman et al., 1987; Skelly et al., 1988). In spite of technical constraints, inflight EEG recording seems to be a promising method.

The electrooculogram varies with level of alertness and can also be used to determine eye position. Studied alone or in conjunction with the heart rate, it can be used to evaluate workload in various flight phases (Wilson and Fisher, 1991). It has also been found useful in display evaluation (Wilson, Hughes and Hassoun, 1990) and comparisons between two different aircraft sensor systems (Wilson, Badeau and Gawron, 1993).

Other psychophysiological parameters can also be analyzed to evaluate the man-machine interface: voice command, respiratory frequency, motor activity, etc. Some of these are described in the appendix, others can be discussed with the researchers whose names are listed in the register of teams working on these subjects.

Mental Load

Mental workload is a concept that relates operator capacity to the performance of a task(s). Several approaches have been used to measure mental workload including psychophysiological techniques (Kramer, 1991; Wilson and Eggemeier, 1991; and Wilson and O'Donnell, 1988). The assumption is that the operator utilizes more resources to accomplish the task as mental workload increases, and that this mustering of resources requires physiological mechanisms and therefore can be detected with psychophysiological measures (See Gopher and Donchin, 1986; and O'Donnell and Eggemeier, 1986 for reviews).

The most frequently employed physiological measures of operator workload include: (1) heart rate, (2) respiration, (3) eyeblink, (4) electroencephalogram, (5) evoked cortical response, and (6) measures of hormonal levels.

Heart rate measures have been frequently used to assess workload in either simulated or actual flight environments. The use of heart rate to measure pilot responses to flight was reported as early as 1917 (Gemelli, reported in Roscoe, 1992). A number of flight studies since then have produced two general findings, (1) heart rate provides a measure of workload for the different flight segments, i.e., take-off, weapons delivery, landing, cruise, etc.; and (2) the pilot in control of two-pilot aircraft has higher heart rates. Generally, high cognitive demands are associated with higher heart rates. Heart rate has also been used as a debriefing tool during test and evaluation flights (Rokicki, 1987; Roscoe and Ellis, 1990). Heart rate measures have gained acceptance to the point that they have been used as part of the criteria for government certification of several commercial aircraft (Blomberg, et al., 1993; Roscoe, 1987a; Speyer, Fort, Fouillot and Blomberg, 1987; Wainwright, 1988).

Physical effort causes increased heart rates but the mental workload effects are seen as being separate to these. Blix, Stromme and Ursin (1974) found that heart rate exceeded the rate expected due to strictly physiological demands as measured by oxygen consumption from helicopter and transport aircraft crews. They termed this the "additional heart rate" which was the heart rate beyond that required to meet the metabolic needs.

Heart rate has also been used to measure workload in non-aviation situations. These include: automobile drivers (Taggart, Gibbons and Somerville 1969; Littler, Honour and Sleight 1973; Lecret and Pottier 1971; and Helander, 1975), race boat drivers (Johnson, 1980), and personnel engaged in a simulated radar watch (O'Hanlon and Beatty, 1977).

Heart rate variability has been used to measure operator workload during simulated flight (Itoh, Hayashi, Tsukui and Saito, 1989; Lindholm and Cheatham, 1983; Lindqvist, Keskinen, Antila, Halkola, Peltonen and Valimaki, 1983; Opmeer and Krol, 1973; Sayers, 1973) and during actual flight (Sekiguchi, Handa, Gotoh, Kurihara, Nagasawa and Kuroda, 1979; Wilson, 1993 and 1992a). As a rule, heart rate variability is reported to decrease with increased mental demands. Several laboratory studies have reported similar results (Aasman, Mulder and Mulder, 1987; Mulder, 1980; Mulder, 1988; Mulder, 1992; Vicente, Thornton and Moray, 1987). However, not all reports show these trends and suggest that heart rate is a better measure of operator workload (Wilson, 1993).

Respiration rate has been found to increase when cognitive demands become greater in several flight and simulated flight studies. These include: Fraser (1964), Harding (1987), Haward (1967), Kirsch (1945), Lewis et al. (1967), Lindholm, Cheatham, Koriath and Longridge, (1984), Opmeer and Krol (1973), Roman (1963), and Wilson, Fullenkamp and Davis (in press).

Endogenous eyeblinks, in contrast to reflexive blinks, have been found to vary as a function of the level of visual attention to a task with higher visual attention associated with lower blink rates and shorter duration blinks. Wilson et al. (1987) found variations in blink rate as a function of flight segment with lower rates in higher visually demanding segments. Stern and Skelly (1984) reported decreased closure duration when flight duties were assumed by either the pilot or copilot in a B-52 flight simulator. Wilson and Fullenkamp (1991) reported a reliable decrease in blink rates with more demanding fighter aircraft mission segments while Sirevaag, Kramer, deJong and Mecklinger (1988) reported that eye closure duration decreased in multi-task situations relative to single-task conditions. Wilson, Badeau and Gawron (1993) on the basis of eye blink data, reported that target detection was more difficult for radar vs infrared systems during training flights.

Multi-task environments such as car driving, for example, have produced decreased blink rates in city vs. highway driving (Lecret and Pottier, 1971; Pfaff, Fruhstorfer and Peter, 1976). In contrast, increased blink rates have been reported as a function of time-on-task for automobile driving (Pfaff, Fruhstorfer and Peter, 1976) and simulated driving (Biedeman and Stern, 1977). Fruhstorfer, Langanke, Meinger, Peter and Pfaff (1977) reported that blink durations increased during expressway driving when compared to highway driving. Torsvall and Akerstedt (1987) reported increased incidence of slow rolling eye movements in train drivers during night time journeys. Not all studies using eye blink measures report findings consistent with the above results (Casali and Wierwille, 1983). However, some of the discrepancies may be due to procedural differences (See Wilson and Eggemeier, 1991).

Eye point-of-regard measures have also been used to monitor eye activity during complex task performance related to mental workload in actual or simulated flight (Cote, Krueger and Simmons, 1985; Fitts, Jones and Milton, 1950; Gainer and Obermayer, 1964; Harris, Tole, Stephens and Ephrath, 1982; Simmons, Lees and Kimball, 1978; Tole, Stephens, Harris and Ephrath, 1982; Wilson, O'Donnell and Wilson, 1983) and driving environments (Hughes and Cole 1988; Mourant, Rockwell and Rockoff, 1969; Mori and Abdel-Halim, 1981; Mori, Tanaka and Abdel-Halim, 1977; and Sivak, Coon and Olson, 1986).

Electrical brain activity, as measured by the EEG, has been successfully applied to monitor alertness and the incidence of sleepiness in several situations including flight and simulated flight (Mollard, Coblentz and Cabon, 1990; Natani and Gomer, 1981; Sirevaag et al., 1988; Sterman, Schummer, Dushenko and Smith, 1987), radar operation (O'Hanlon and Beatty, 1977), and driving (Torsvall and Akerstedt, 1987; Fruhstorfer, Langanke, Meinzer, Peter and Pfaff, 1977). Several investigators have reported data that demonstrate sensitivity of either the alpha or theta EEG bands to variations in the workload associated with task performance. Decreased alpha and increased theta power is typically associated with high workload conditions.

A few investigators have applied evoked potentials as indices of workload in multi-task environments using the transient evoked response during flight (Wilson and Fullenkamp, 1991; Wilson, Fullenkamp, and Davis, in press), simulated flight (Lindholm et al., 1984; Kramer et al., 1987; Natani and Gomer, 1981), and automobile driving (Janssen and Gaillard, 1985). These studies report changes in evoked potential amplitudes with changing task demands. However, there is a lack of consistency in the results at this time.

The measurement of certain body fluids can provide an index of operator state and workload (Frankenhaeuser, 1975). In laboratory studies with single-task paradigms it has been demonstrated that hormone level changes as a function of task difficulty both between (Fibiger, Singer and Miller, 1984) and within mental tasks (Fibiger, Evens and Singer, 1986). In the flight environment, catecholamine levels were found to be raised as a function of: the stresses of flight itself, long duration flights, level of experience, degree of responsibility and the handling characteristics of the aircraft (Miller, 1968). Miller, Rubin, Clark, Crawford and Arthur (1970) reported that pilots showed greater increases in these hormones after practicing carrier landings than did the Radar Intercept Officers, or following ground landings that simulated carrier landings. Higher mental workload has been associated with increased adrenaline levels in bus drivers (Mulders et al., 1982), sawmill workers (Johansson et al., 1978), air traffic controllers (Melton, Smith, McKenzie, Wicks and Saldivar, 1978), and rest-day vs daily-work routines (Jenner, Reynolds and Harrison, 1980). Further, some authors have developed a measure of mental workload which is the ratio of noradrenaline to adrenaline (NA/A) (Fibiger, Singer and Miller, 1984). Fibiger, Christensen, Singer and Kaufmann (1986), in a study with sawmill workers, reported that workers with jobs having the highest mental workload showed lower NA/A ratios than individuals with lower mental workload jobs. Nakamara, Kakimoto, Tajima, Tarui and Yagura (1989) reported that in pilots and copilots flying military transports, copilots evidenced lower NA/A ratios compared to pilots. Kakimoto et al., (1988) measured salivary cortisol following important transport flight events such as take-off and landing and found increased cortisol levels and increased heart rates to the more demanding aspects of flight. The more demanding role of being in charge of the aircraft by either pilot or the copilot also caused increased levels of cortisol and increased heart rate.

Psychological Stress

Stress has been defined as, "the nonspecific response of an organism to any demand made upon it," by Selye (1973). In other words, stress is a state of disharmony or threatened homeostasis. Stress reactions occur when there is fear of loosing control over the situation and uncertainty over the outcome of the ongoing events. The blocking of intentions and aspirations causes increased arousal, overreactivity, and negative emotions (anxiety, irritability, anger, etc.) that disrupt the subtle equilibrium (homeostasis) between psychological and physiological processes. Both physical and emotional stressors set into motion physiological responses designed to preserve the dynamic equilibrium of the body (i.e., homeostasis). However, stress-induced overreactivity of the psychophysiological system creates several problems: 1) difficulty maintaining concentration on a task, 2) increased energy mobilization above what is actually needed to perform the task, 3) activation of energetical mechanisms unnecessary to task execution (i.e. increased muscle tension which may lead to headaches), and 4) prolongation of activation which persists even after the task has been completed. Stress-related disturbances often become manifest as psychosomatic complaints and sleeping problems. Chronic stress may lead to pathophysiological processes (Gaillard and Wientjes, 1993).

Because stress is a relative concept, a given stressor does not exert the same effect on each individual. Of course, not all states of stress are noxious, and stress sometimes might even be perceived as pleasant or exciting, which may increase motivation, challenge the individual, and stimulate growth and maturation (Chrousos and Gold, 1992; Humphrey, 1978; Picano, 1986). However, particularly in highly demanding work environments, the concern is more often on states of stress which are associated with negative emotional responses. The severity of stress reactions depends on how the individual evaluates the stressful situation and how personally vulnerable he/she is to negative stress responses. Individual emotional responses are determined by personality factors such as ego strength, defense/coping strategies, and motivational levels. Military pilots perceive the risks of flying relatively less because of their personalities and high motivation (Cetinguc, 1992). They are believed to be healthy, hardy, non-neurotic individuals who cope by seeking information and constructive solutions, arguing, joking, sometimes ignoring threat, suppressing feelings, and acting out frustrations (Picano, 1990; Picano, 1991; Ursano, 1980; Ursano and Holloway, 1985). However, even the most resistant individuals do have a breaking point when confronted with overwhelming stress conditions (Carson, Butcher and Coleman, 1988; Cetinguc, 1992; Hordern, 1985; Hobfoll, 1988). Once that breaking point is reached, anxiety, depression, boredom, fatigue, fear, substance abuse, psychiatric disorders, bad professional performance, and even accidents may result (Chorusos and Gold, 1992; Hawkens, 1987; Hordern, 1985; Humphrey, 1978; Jones, 1990). It has been suggested that an "inverted U shape" function reveals stress-performance relations, and this shows that performance is best at certain optimal levels of stress but performance deteriorates when the stress is too low or too high (Cetinguc, 1992; Picano, 1991).

It is important to make a distinction between mental load and stress as two biobehavioral states that have different characteristics. High workload is an important but not a critical factor in the development of stress symptoms because stress may also occur in conditions of underload and outside the work environment. Mental load and stress are both characterized by a potential discrepancy between demands and resources. Since it is uncertain whether this discrepancy can be resolved, it results in energy mobilization. Mental load and stress differ, however, in the way the individual responds to the situation (Gaillard and Wientjes, 1993): 1) Under mental load, extra energy is mobilized via mental effort that focuses attention and improves performance efficiency. Under stress, the increased activation is distracting, dysfunctional, and reduces efficiency. 2) Under mental load, energy mobilization is guided by the demands of the task and is limited to the period the task has to be executed; the increased activation returns to a resting level after the task has been completed. In a stress state, the activation persists outside the task situation and inhibits recovery. Activation may even continue when the trigger for the stress responses no longer exists. 3) Mental effort is oriented towards the execution of the task, whereas stress is oriented towards self-protection. Under mental effort the situation is experienced as a challenge which is accompanied by positive emotions and feelings of accomplishment and "positive fatigue." Under stress the situation is experienced as threatening and results in strain and negative emotions.

The state of stress should also be distinguished from the effects of physical stressors in an adverse environment. Certainly aviators are exposed to a cocktail of stressors during the performance of their jobs (Gaillard and Wientjes, 1993). Acceleration, hypoxia, noise, vibration, heat/cold, sleep deprivation, jet-lag, etc., are well-known physical stressors peculiar to the flight environment. All have direct effects on the body and the physiological system, and in this way affect the performance and mood of the operator. Along with these physical stressors, there are domestic stressors (family separation, debt, marital problems, etc.) which act upon the pilot since he/she has other roles in the society such as husband/wife, father/mother, or employee. Even the routine tasks in the aircraft may cause strain since pilots are often subjected to sitting for long periods of time in their working environments, completing endless routines, and facing the continuous possibility of emergencies (Perry, 1971). Fortunately, aviators often are able to effectively cope with these kinds of stresses, but it requires consistent effort for those who live a life of deadlines (Hawkins, 1987) and constant demands. Their stresses deserve a thorough understanding because they are at the heart of flight safety.

Although it is difficult to precisely quantify the magnitude of environmental and individual sources of stress and reactions toward stress, there are several early indicators of unfavorable stress responses. In attempting to evaluate stress, several factors should be considered: 1) the relation between work demands and work characteristics; 2) the physiological reactivity of the individual; and 3) the person's subjective experience of the situation. Thus, the evaluation should include both physiological and psychological components (Cotton, 1990; Hawkins, 1987; Picano, 1991; Sive and Hattingh, 1991).

Physiological and biochemical analyses can offer insight into disturbances in the individual's functioning (Hawkins, 1987; Sive and Hattingh, 1991). Observation of end-organ physiological responses can determine overall sympathetic activation via the use of heart rate, blood pressure, muscle activity, and skin conductance. Biochemical analyses of blood, urine, and saliva components can also reveal stress-related changes in catecholamines, norepinephrine, dopamine, uric acid, hematocrit, blood density, and other parameters as mentioned later in the section on bodily fluids.

Psychological evaluations add a further important assessment dimension, especially in cases where the stress has been chronic. Paper-and-pencil measures such as mood scales, personality questionnaires, and symptom checklists, are all invaluable for the assessment of subjective feelings, anxiety, negative affect, impulsivity, etc. However, caution should be used in interpreting results since subjects may minimize or exaggerate problems (consciously or not), cultural biases may distort or invalidate results on certain populations, or test scores may provide only a non-specific indication of some problem. Comprehensive interviews are often necessary to ensure the validity of conclusions based upon psychological tests.

It appears that unidimensional measurement of stress is too simplistic. Instead, a multidimensional approach is needed in which both paper and pencil tests and interview results are correlated with physiological and biochemical concomitants of stress. These measures should be obtained not only during work but also after work to assess recovery. For comparison purposes, measurements may also be obtained in standardized and simulated task conditions. In general, the focus should be to measure awareness and patterns of reactivity to stressors and to determine whether or not there are disruptions in normal functioning (Sive and Hattingh, 1991; Wheatly, 1985).

Sleep

Sleep is characterized by the alternation of non-REM and REM periods, sometimes with intermittent waking periods (e.g. Nicholson and Stone, 1982; Horne, 1988). Several models have been proposed that explain the occurrence of non-REM/REM cycles, the circadian dependence of REM sleep, and the correlation of deep sleep (slow wave sleep) with prior waking time (Borbély and Achermann 1992). Important application areas of sleep research are studies of short sleep periods, in particular daytime naps (Stampi, 1992), sleep medication (Nicholson and Stone, 1982), and sleep after transmeridian flights (Wegmann et al., 1986).

Sleep is generally assessed by sleep polygraphy, a combination of EEG, electrooculogram (EOG), and EMG recordings (Rechtschaffen and Kales, 1968). From sleep polygraphies, various measures of sleep quality and sleep regulation can be deduced. The amount of slow wave sleep shows a close link to existing mathematical models (Akerstedt and Gillberg, 1986). If only times of sleep-onset and wake-up are to be determined and the structure of sleep is of minor interest, the measurement of body activity, e.g. wrist activity, may be sufficient (Buck et al., 1989).

Examinations of the sleep cycle are essential in clinical settings for determining the presence of sleep and arousal disorders such as narcolepsy, idiopathic hypersomnia, sleep apnea, motor abnormalities (periodic movements in sleep or fragmentary non-REM myoclonus), recurrent hypersomnias, pseudohypersomnias, a variety of insomnias (acute situational, chronic, drug-related, etc.), and other problems (Broughton, 1987). In the research realm, sleep studies can provide insight into circadian cycle disruptions, drug effects, environmental stressors, and other factors which may indirectly affect waking alertness by disrupting normal sleep quality.

Vigilance/alertness

Alertness and vigilance are often used synonymously along with terms such as arousal and attention to describe states of activity of the brain that affect performance and behavior. Alertness and arousal are relatively non-specific concepts and may be viewed as tonic sustained cerebral activation arising from the influence of subcortical structures. Vigilance however has a more directly behavioral connotation and involves sustained readiness to detect and respond to changes in the environment. It is an active, performance related process involving perception of stimuli, processing of information, and readiness to respond. Attention is clearly a component part of vigilance and is relatively specific.

The degree of alertness or arousal clearly influences vigilance but does not imply responsiveness to stimuli. The environment plays an important role in maintaining vigilance and stimulating activity can overcome low alertness although perhaps only on a temporary basis. A high level of alertness does not necessarily imply vigilance unless attention is directed appropriately.

Alertness and vigilance have been investigated using many psychophysiological measures. The spontaneous EEG is one of the most frequently studied, and in addition to its having well defined characteristics during sleep, it may be used to identify drowsiness during periods of work. Vigilance has been studied using both the spontaneous EEG and event-related potentials. Patterns of EOG activity including blink activity and eye movements change with drowsiness and reduced alertness (Andreassi, 1989; Stern and Dunham, 1990).

Specific factors which change alertness and vigilance have been studied by psychophysiological methods, although such measures should be accompanied by direct objective and subjective measures. These include changes related to irregular or extended schedules of work and the effects of drugs such as sedative and stimulant compounds. Environmental factors such as noise and hypoxia that may influence vigilance have also been investigated.

Since the first experiments of Berger in the 1930's, it has been clear that onset of sleep and drowsiness are accompanied by changes in the appearance of the EEG and in its power spectrum. During sleep, large changes also occur in the amplitude and time course of the auditory evoked response. The correlation between sleep and changes in the EEG spectrum is sufficiently robust that in many studies sleepiness has been defined according to the characteristics of the EEG. Through most of the history of EEG research, computers sufficiently powerful to analyze the large amounts of data collected in EEG experiments were not generally available, and visual analysis of paper tracings, or simple numerical analyses were the only tools available to EEG researchers. This situation is now fast changing. Using new, high speed computers, and applying signal processing algorithms developed for radar and medical imaging, researchers now have the technology to make rapid progress in both basic and applied EEG research. The number of papers being published in the area of EEG and event-related potentials (ERPs) is currently more than 300 per month, and the number of documented EEG-based measures of cognition is also increasing. However, relatively little basic or applied research has directly studied the relationship between EEG and ERP measures and concurrent changes in cognitive performance.

CHAPTER 3
ATTRIBUTES OF MEASURES

A wide variety of practical techniques now exist to assess psychophysiological parameters. In recent years the application of computer based methods of analysis has become well established, and psychophysiological techniques are increasingly used to investigate the effects of behavioral stressors related to the aviation environment. However psychophysiological parameters vary according to circumstances, including between and within individual variability, time of day, and method of testing. Consequently, it is important to be able to relate changes in psychophysiological parameters to objective behavioral outcomes.

The purpose of this chapter is to review the attributes of each measure so that for a particular research application the most appropriate measures may be selected. Each measure will be considered according to its reliability, validity, diagnosticity, specificity, and sensitivity. An overview of these criteria based on O'Donnell and Eggemeier (1986) is presented below.

Reliability reflects consistency of results, in terms of between-test error for tests repeated on different occasions. An estimate of a measure is taken, for example an average of a series of signals, and the correlation between averages obtained on separate days at the same time of day in the same subject gives an index of reliability.

Validity indicates the degree to which a test measures what it is intended to measure and provides an answer to the question posed. To a large extent, this depends on the specificity of the measure, but is also related to the applicability of previously reported experimental research.

Diagnosticity is the extent to which a technique indicates the mechanism or process that causes a change in a measure. For example, end-tidal CO_2 can be directly related to hyperventilation whereas increased heart rate is affected by many different factors. This is closely related to the specificity of the measure, or how well a specific variable directly measures the activity under investigation. For instance, heart rate is a manifestation of the function of the heart and the EEG directly measures brain activity. However, often variables are regarded as markers rather than direct measures as is the case with cardiovascular parameters which indirectly measure fitness, mental load, or physical effort.

Sensitivity is the capacity of a technique to discriminate between different levels of a stressor (i.e. different doses of a drug or changes in workload) and to detect deviations from an optimal state, such as reduced fitness or impaired alertness.

Additionally, the level of intrusiveness and operator acceptance will be discussed. To be useful, the measurement technique should not interfere with the operator's task or cause undue irritation. This is of particular concern when dealing with professionals such as aircrew.

All of these criteria deserve attention during the planning phase of each investigation. Careful consideration of each metric, its relative advantages and disadvantages, and its applicability to the specific problem under investigation will ensure that the best measure or combination of measures is chosen. In the following pages, each measure included in this report will be discussed in relationship to the criteria presented above. Once the reader has decided on the best measure(s) to use, specific implementation information can be found in the appendixes.

Activity

While activity measures may not be universally regarded as a type of "psychophysiological" measure, a discussion of activity monitoring is included here because these data are often collected in conjunction with physiological measures. The motor activity of a subject is often measured in studies concerned with vigilance, jet lag and shift work schedules. However, this parameter should always be used and interpreted with care. For example, lack of motion does not necessarily reflect a decrement in vigilance. There are also significant intra-individual differences which require the knowledge of a reference control situation.

The evaluation of actimetry is nevertheless a practical and reliable method to study circadian patterns in human activity, and recent investigations have claimed that it could be a fruitful approach to the study of sleep. Numerous techniques have been developed with two of particular interest for aviation and space research: ambulatory actimetry where an actimeter is worn on the wrist, and actimetry done by the processing of video pictures. Both of these techniques will be described further in Appendix A. Results yielded by these two techniques should always be interpreted with respect to the experimental or operational situation (Parkes, Kayed, Schulz and Tobler, 1992).

Actimetry may be used in numerous operational contexts since the required equipment is small. It is best suited for investigations of circadian rhythms of activity, wake and sleep. Actimetry has numerous applications in the fields of aviation and space. In the laboratory it can be implemented to assess the effects of the administration of different psychotropic substances upon the motor activity of subjects (Aguirre, Benoit, Denise, Keromes, Cherbit and Goldenberg, 1992). It can also be used to complement or as a substitute for EEG in sleep studies (Lowden and Akerstedt, 1992), or to explore the behavior of subjects placed in an unusual environment such as long term confinement (Tobler and Borbely, 1992). In the field the measure of motor activity, especially by wrist actimetry (with the use of questionnaires), is often the only measure which can be obtained without disturbing the ongoing mission. Thus, it can be applied to an aircrew flying a transmeridian flight (Lowden and Akerstedt, 1992). It can also be used on subjects exposed to new "Zeitgebers" such as subjects who have to accomplish a mission in the Arctic environment where daylight time varies greatly at different times of the year (Buguet, Rivolier and Jouvet, 1987). These observations are useful to evaluate the duration of the effects of this desynchronization on motor activity and the rapidity of resynchronization.

Methodology. The detection of wrist motion is usually accomplished with commercially available equipment which can consist of a small wristwatch size accelerometer/recorder. This motion logger is initialized from a computer where parameters are established to control the duration of data collection, the collection mode (zero crossing or time-above-threshold) and the inclusion or exclusion of event markers within the recorded data. At the end of the experiment the data from the motion logger is downloaded to a computer.

Other in-house systems have been developed that use strain gauges. A thin strip of steel is attached over the wrist of the subject--one end on the hand and the other on the arm. Signals from the strain gauges are amplified, filtered and recorded on a small tape recorder or transmitted by a telemetry system. At the end of the experiment, the tape recorded signals are read into a computer and the data are analyzed. Zero crossing or time-above-threshold are defined by the user on the computer.

With the use of video display sensors the subjects are filmed with one or more video cameras. Virtual sensors are defined on each video signal coming from the cameras. The operator chooses the placement, number, size and sensitivity of the software sensors which detect contrast variations. All motion in the area of a sensor is detected and recorded by a micro-computer with an in-house developed computer program. The activity is expressed as the number of seconds having motion.

Processing of video frames on micro-computer is similar to the above method. The subjects are filmed with one or more video cameras and these cameras are connected to a digitization card in a micro-computer. This card makes a number of real time calculations for comparison of successive frames. A computer program specifically developed for the ongoing experiment uses contour extraction to quantify the subject's motions.

Sensitivity and Diagnosticity. The sensitivity of actigraphy by the detection of wrist motions is essentially a function of the threshold level fixed as the detection limit. So it can be variable from one experimental environment to the another. If vibration or acceleration is present in the experimental environment, the threshold will have to be fixed at a high level so the sensitivity will be low.

For typical commercial equipment, an analog filter is used which has a band pass between 0.16 Hz and 10.0 Hz and at least two different threshold settings available.

Methods based on strain gauges are less sensitive and there are other factors that can further reduce their sensitivity such as temperature or humidity variations. The data are typically expressed in percentage of the full scale. Ranaivosoa, Cnockaert and Lepoutre (1990) report mean sensitivity of 1.3% of the full scale or 1.7° of motion.

Actigraphy with the use of video display sensors using commercial equipment permits the use of from 1 to 4096 sensor markers for each frame. The markers have a square form and the sensing point is situated below the bottom of the left-hand corner of each sensor. The sensitive area for each marker can be adjusted from 1 to 16 dots. The degree of sensitivity of each point can be adjusted in 8 steps.

The processing of pictures on a micro-computer depends on hardware and software parameters. The hardware parameters are those of the digitization card. The resolution in pixels can be between 256 x 512 and 4096 x 4096. The number of grey levels is determined by the card and generally varies from 64 to 256. Colors can also be analyzed. The number of color levels ranges from 64 x 64 x 64 to 512 x 512 x 512.

The quality of the hardware is important and the resolution of the algorithm can be variable from one system to the other, from 2 to 4 pixels or more. Sometimes, the operator has to choose between good resolution with good sensitivity and lower resolution with a higher speed of analysis.

Wrist motion actigraphy is specific to locomotion activity rather than the total movement of the subject. Since different body sites are in motion with different types of activity, sites other than the wrist may be used to attach the actigraph sensor (Tyron, 1991). However, it is possible to monitor subjects while awake or asleep. With actigraphy using video display sensors it is possible to quantify total subject activity, the total simultaneous activity of several subjects, and the activity of a particular area in a picture. Actigraphy by processing video frames on a micro-computer provides for the same types of studies as using video display sensors with the added capability of being able to quantify the activity of one or several limbs, and to follow motion.

Intrusiveness/acceptance. The three methods are non-intrusive and present no acceptance problem. For the two video methods, the subjects can move freely. The only constraint is that they stay in the field of view of the camera.

Reliability. The reliability of the wrist motion method depends on its diagnosticity and on the selected level of sensitivity. In order to compare two different records, the threshold level and the time-above-threshold have to be correctly set to limit artifact detection in both records. The criteria used by all researchers must be the same to maintain reliability. Patterson, Krantz, Montgomery, Deuster, Hedges and Nebel (1993) performed studies to evaluate the reliability and validity of the wrist actigraph. Their subjects engaged in various physical and sedentary activities. The actigraph very reliably differentiated between various activities, both physical and sedentary. They further recorded oxygen uptake and heart rate and found that actigraph data were significantly correlated with these measures. Further, the test-retest reliability of the actigraph measures were examined and found to be very high, r=.98. They concluded that the actigraph is a very useful device for behavioral and biomedical studies and suggested that other body sites may be more appropriate for sensor placement than the wrist depending upon the nature of the activity.

The fidelity of angle measurement has been tested by Ranaivosoa, Cnockaert and Lepoutre (1990) for strain gauge sensors on 76 subjects during 4 hours of continuous recording. The average of the root mean square values was 5^{o} or 3.7% of the full scale.

With the use of video display sensors, the criteria used by researchers must also be the same from one experiment to another to maintain reliability. It is needless to say that the activity of the subject will not be recorded if he/she is out of the sensor area. This means that the choice of the activity area is very important, as is the choice of the sensitivity level of the sensors which depends on the amount of variation of the ambient infra-red light during the experiment.

Processing of pictures on micro-computer is a powerful and reliable method if one continuously maintains good contrast between the subject and the environment. If this is not possible, one must place reflecting points on the subjects so their motion can be followed.

A potential artifact of this method is the exclusion of fast movements due to the time required to execute the picture extraction. This artifact is a function of the speed of the computer used and of the algorithm complexity developed for data extraction. Nevertheless, with constant technical improvements and computer performance increases (and price decreases) this artifact is becoming less of a problem.

Applicability. Wrist motion can be used in ambulatory monitoring on subjects at home and on their jobs with the limitations given in the sensitivity, diagnosticity and reliability paragraphs. Video display sensors can be used to follow real time variations of activity, or can be used on recorded video pictures. However, records must be of good quality. Processing of video frames on micro-computer requires the writing of appropriate computer software (Sprijt and Gispen, 1983; Crawley et al., 1982) because of the lack of standardized commercial software.

Actimetry is generally considered a simple measuring tool to evaluate the activity and sleep of individuals, especially during long term recording sessions and under extreme environmental conditions. However, when possible it is useful to collect other variables simultaneously in order to provide a better assessment of the effects of the independent variable(s). In studies of sleep and/or vigilance, for example, it would be very useful to add electroencephalographic (EEG), electro-oculographic (EOG), or electromyographic (EMG) recordings in order to determine the various electrophysiological stages of sleep and wakefulness. Behavioral data provided by the video recording method can be a useful measurement of motor activity in most research studies, especially those on vigilance and fatigue. Also, the use of questionnaires on sleep or behavior can yield interesting correlations.

Electroencephalography

Since Berger's 1929 discovery of electrical brain activity in humans, there has been extensive research aimed at linking EEG changes to mental events, personal attributes, and behavioral characteristics (Shagass, 1972). Electroencephalographic measures are used in laboratory studies and in field studies to examine the impact of environmental, work-related, physical, pharmacological, and other types of manipulations on the electrical activity of the brain. Investigators can evaluate brain activity either through the spontaneous EEG or through event-related potentials (also referred to as evoked responses). The attractiveness of studying the EEG stems from the fact that the electrical state of the brain offers information about central nervous system (CNS) functioning which underlies mental and psychological functions. Any variable which significantly affects the EEG can be expected to affect aspects of functioning including, for example, the accuracy and speed of mental judgements, the level of vigilance and/or behavioral arousal, and the emotional status of the individual.

Methodology. EEG signals are detectable from a variety of scalp locations using small electrodes (8 mm) constructed of silver-silver chloride, gold, or tin. Electrodes are attached to clean scalp placements with tape, collodion, or paste, and are filled with an electrolyte solution. Electrical activity is then recorded with 2 or more electrodes (depending on how much of the brain's surface activity is of interest) by amplifiers capable of amplifying 5-100 microvolt signals which oscillate at 0.5-100 Hz. Amplified data may be displayed on an oscilloscope, an ink-writing oscillograph, or a computer CRT. If a computer is used to sample and store the data for analysis, a sampling rate of 3-5 times the highest frequency of interest is necessary to preserve an accurate representation of the original EEG (higher frequencies which may be present should be filtered out prior to sampling). Recorded data may be scored via visual inspection or by computerized procedures such as power spectral analysis. In either case, the recording is usually reduced to a table of values which represents the relative amount of EEG falling within each of 4 distinct bands: delta (1-3 Hz), theta (4-7 Hz), alpha (8-12 Hz), and beta (13-20 or 30 Hz). Also, the dominant or peak frequency observed during specified time frames is often determined. The normal adult waking EEG contains each of these different rhythms, but the most prominent is the alpha rhythm which is blocked by opening the eyes, cognitive activation, sudden arousal, and sleep. Beta waves also contribute substantially to the normal awake EEG, whereas slower activity (below 8 Hz) is usually predominant only during sleep (Cooper, Osselton and Shaw, 1980). See Appendix B for more details on EEG collection procedures.

Event-related potentials (ERPs) are recorded with the same electrodes and amplifiers used for EEG. However, rather than focusing on a continuous recording of spontaneous activity, the focus is on EEG activity which is related to (or evoked by) specific stimulus events. The potentials that are recorded for subsequent analysis are obtained by time-locked averaging of short EEG epochs where the averaging is "triggered" by the presentation of a stimulus event.

Another type of EEG data can be thought of as being midway between the time-domain (ERP) and frequency-domain (spectral) approaches. By stimulating at high repetition rates (e.g. 40 per second in the auditory modality, or near 10 Hz in the visual) driven steady-state responses (SSRs) can be measured using either time-domain, or more often, frequency-domain methods (Regan 1989, Galambos and Makeig, 1987). SSRs can be compared to both EEGs and ERPs in that, like ERPs, they are evoked (or driven) by sensory stimulation; and like EEGs, they can be collected continuously and are conveniently studied using frequency domain methods.

Sensitivity and Diagnosticity. Spontaneous EEG assessments are useful in studying the changes in alertness or arousal which occur when individuals transition from wakefulness to sleep (Shagass, 1972). Also, it is well known that there are characteristic EEG patterns associated with general relaxation (increased 8-12 Hz activity) and alertness (increased 18-30 Hz activity). EEG assessments have proven worthwhile in clinical assessments of epileptic seizure disorders (Niedermeyer, 1987), and psychiatric problems (Small, 1987), and the sensitivity of EEG to the effects of drugs such as barbiturates, stimulants, benzodiazepines, and tricyclic antidepressants is well known (Bauer, 1987). More recently developed topographic mapping techniques, where over 20 channels of EEG are digitized, analyzed, and converted to color maps of brain activity, have been useful in detecting subtle neurological problems in patients who are suffering from depression, Alzheimer's, schizophrenia, and other diseases (Braverman, 1990). Investigators have used EEG assessments to explore a wide range of operationally relevant problems. There has been considerable interest in using EEG data to assess the impact of various stressors on aviators, astronauts, and divers (Frost, 1987). Thus, from the standpoint of examining global levels of arousal or activation, EEGs play an important role.

Several studies have endeavored to determine the relationship between EEG activity and cognitive task performance. One general finding is that alpha power decreases with task performance. This has been reported with a verbal classification task (Pfurscheller and Klimesch, 1987), increasing levels of difficulty in an arithmetic task (Earle and Pikus, 1982), learning to recall digit strings (Lang et al., 1988), and visual and auditory memory tasks (Kaufmann et al., 1992). A second finding has been increased theta power during periods of mental activity in concept learning (Lang et al., 1988), performing a spatial and verbal task--with larger increases over the right hemisphere in the spatial task--(Rugg and Dickens, 1982) and during a semantic memory search task (Mecklinger et al., 1992). There also exists evidence that frontal theta activity is associated with an increase in general mental processing during challenging tasks (Gundel and Wilson, 1992). EEG spectra have been shown to be strongly related to changes in performance on simple detection tasks as well (Makeig and Inlow, 1993). Further research needs to determine to what extent the relation between EEG changes and task performance changes varies according to the nature of the task. A conservative assumption is that EEG changes reflect only changes in global brain state on a single wake-sleep continuum.

Event-related potentials and steady-state responses are quite useful as well. Changes in ERPs have been observed to occur as a function of reduced alertness and drowsiness. Such changes include reduced amplitude of the P300 component and reduced amplitude of the contingent negative variation. The P300 is associated with stimulus-related attentional processes, and consists of two components, the frontally distributed earlier P300 and the parietally distributed later P300. Changes in the earlier component are associated with orienting to novel stimuli, while the later is more sensitive to attentional processes. P300s to task stimuli in cognitive tasks have been reported to change as a function of the nature of the task and task difficulty (Ullsperger, et al., 1987, Kramer, 1991). Other components of the ERP have been used in laboratory and flight studies to monitor brain activity. Wilson, Fullenkamp and Davis (in press) reported that the P200 component was reduced in amplitude when F4 pilots were flying the aircraft compared to when the weapon systems officer (WSO) was flying the aircraft. The CNV, usually elicited in response to a stimulus pair where the first stimulus acts as a warning and the second as an imperative stimulus, is generally considered to reflect two processes. The earlier component of the waveform consists of an alerting response to the warning stimulus, while the later response reflects a preparatory, readiness process. The utility of SSRs has been demonstrated in research on automated fitting of eye glasses (Regan, 1989), but the usefulness of SSRs in cognitive studies is less well established. For example, while the 40 Hz auditory SSR has lower amplitude during sleep, it may not be much more sensitive an indicator of alertness than the concurrently recorded EEG at adjacent high frequencies which can be recorded concurrently (Makeig and Inlow, 1993). Event-related perturbations in auditory and visual SSRs, however, can be studied using a measure known as the complex ERP or CERP (Makeig and Galambos, 1989). The CERP is independent of the ERP, which can be measured concurrently, and has been shown to vary with workload and level of attention (Rohrbaugh et al., 1989). Correlations between SSRs and cognitive processing speed in a memory task have been reported by Wilson and O'Donnell (1988).

Intrusiveness/acceptance. Since EEG, ERPs, and SSRs can be collected with electrodes that are affixed to the surface of the scalp, recordings are considered nonintrusive. Furthermore, spontaneous EEG data can be monitored with ambulatory recorders and radio telemetry units which permit the subject to move freely and go about a normal routine. Since the electrical activity of the brain is spontaneous and does not necessarily require external stimulation or the ongoing completion of some cognitive task, the collection of spontaneous EEG data does not interfere with tasks in which the subject is normally engaged. ERP data also may be collected without interfering with task completion if the triggering stimulus is embedded in the task of interest. SSRs offer possibilities for use in non-laboratory situations as well since it may be possible to stimulate and record SSRs which do not interfere with the completion of work-related tasks. Laboratory and field investigations have demonstrated that EEG electrodes can be tolerated for several days without the requirement for removal and reapplication. One potential problem with the collection of EEG data from pilots is that they may be concerned about the data being used to disqualify them from flight status. The researcher should be aware of this difficulty and make efforts to allay such fears by pointing out that the data will be scored primarily by computer and technicians rather than by clinicians. Also, the aviator should be assured that confidentiality of results will be maintained.

Reliability. Reliable changes in EEG activity may occur in a given individual when repeatedly exposed to the same stressor (or other manipulation), but there may be considerable variability among different persons. However, there is evidence of some consistent effects. Belyavin and Wright (1987) reported that, while EEG changes cannot predict vigilance changes in a straightforward linear fashion, generally there was increased theta and delta activity, and decreased beta activity associated with worsening performance during 15 hours of testing. These results are supportive of the basic arousal hypothesis which suggests an increase of slow-wave EEG as a function of decreased alertness. Further, consistent evidence has been offered by Pigeau, Heselgrave and Angus (1987) who found that increased delta and theta activity was associated with increasing levels of sleep deprivation throughout a 64-hour deprivation period. These results have been confirmed by Comperatore et al. (1993) who reported increases in delta and theta as a function of sleep deprivation. As far as drug effects are concerned, there are reliable EEG changes associated with stages of anesthesia and similar changes are seen during acute intoxication (Bauer, 1987). As mentioned earlier, different classes of drugs tend to have fairly characteristic effects on the EEG as well, and these are observed across different individuals.

Applicability. The sensitivity, reliability, and relative unintrusiveness of EEG, ERP, and SSR recordings make the collection and analysis of this type of data useful in the laboratory and in some field situations. However, particularly when recordings are made while subjects are performing operationally relevant tasks, the investigator must be concerned about signal contamination originating from muscular activity, eye movements, and gross body movements. It is desirable to directly collect both electromyographic and electrooculagraphic data in conjunction with EEG whenever possible to help assess the impact of these confounding signals. Procedures have been developed to remove ocular artifacts from EEG data so that data loss can be kept to a minimum (See Gasser, Sroka,and Mocks, 1985; and Gratton, Coles, and Donchin, 1983). When considering the use of EEG for predicting operationally-relevant performance, it is generally necessary to perform preliminary validation studies in the laboratory (calibration) before going to the field. In this manner, the relationship between performance on the calibration and work tasks can be established at the outset. If the actual work task is much more complex than the laboratory calibration task, the estimate derived may only give a lower bound on work task performance. However, such a lower bound may still be of considerable practical value.

Eyes

Most of the information about the outside world comes to us through our eyes. Eye blinks and eye position are important parameters which can help us understand the visual demands placed on the operator and their responses to these situations. Since input to the eye is blocked during blinks, it is to the human operator's advantage to reduce the number of blinks and the lid closure duration during times of high visual demand. Further, eye point-of-regard can provide data about where information is sought in the environment and about the pattern of eye scanning evidenced in different situations (See Hall and Cusak, 1972; Kramer, 1991; Stern, Walrath and Goldstein, 1984; Stern and Dunham, 1990; and Wilson and Eggemeier, 1991 for reviews).

Methodology. Eyeblinks produce relatively large electrical signals and electrode placement is not critical to capture these signals. Typically, electrodes are placed above and below one eye at the vertical midline to record blinks, although more lateral placements can be used. This allows the placement of electrodes to accommodate helmets, face masks, and other equipment. Blinks are usually detected from digitized data files on computers. Deviations from the non-blink baseline are determined and if they exceed the amplitude and slope threshold then a blink is declared. Amplitude is measured from the eyes-open baseline to the fully closed point. Closure duration can be measured from the half amplitude point on the closing phase to the same amplitude point on the opening phase. Since blinks vary in configuration and their timing is not regular, some investigators scan the data file to check the accuracy of automatic blink detection software.

Eye point-of-regard measures are typically recorded with video or corneal reflection procedures. Eye position is determined and superimposed upon the scene being viewed so that the scan pattern of the eyes can be determined. Additionally, fixation durations can be evaluated, but are time limited by the scan rate of video systems. Automatic scoring methods have been developed to reduce the data analysis time. This method provides accurate records of eye position that are not possible with EOG methods. Appendix C provides more information on recording techniques.

Sensitivity and Diagnosticity. Eye blinks are sensitive to high visual attention demands and also to operator fatigue. Fewer and shorter duration blinks are associated with situations that require intake of important information such as during reading (Ponder and Kennedy, 1928), city driving (Lecret and Pottier, 1971), formation flying (Wilson et al 1987), and landing and weapons delivery in fighter aircraft (Wilson and Fullenkamp, 1991). Blink closure duration has also been shown to be sensitive to high overall task demand. Assuming command of an aircraft is associated with shorter blink durations (Stern and Skelly, 1984) as is flying actual vs simulated missions and flying wing vs lead position (Wilson, et al., 1987). Decreased predictability of the appearance of visual stimuli has been reported to decrease the blink duration (Bauer, Goldstein and Stern, 1987). Blink patterns can also be used to provide information about the operator's responses to environmental stimuli and thus situational awareness (Fogarty and Stern, 1989; Stratton, Wilson and Crabtree, 1993; Stern and Dunham, 1990; Wilson, 1992). Time on task and fatigue have been shown to increase blinking and are associated with longer duration blinks and the appearance of slow eye movements (Bauer et al., 1987; Fruhstorfer et al., 1977; Pfaff et al., 1976; Torsvall and Akerstedt, 1987). However, blinks are not as sensitive to auditory or purely cognitive demanding situations as they are to visually demanding situations (Goldstein, et al, 1985).

Eye-point-of-regard measures are useful to observe eye position as the operator scans the environment. In a cockpit, for example, one could use these measures to determine which instruments are viewed, in what sequence and how long each one was fixated. Fitts, Jones and Milton (1950) reported that important instruments were fixated more often and that longer duration fixations indicated difficulty in obtaining information. Eye scanning patterns have been used to compare cockpit layouts (Gainer and Obermayer, 1964), navigation systems (Cote, Kruger and Simmons, 1985), intertask interference (Tole et al., 1982), and instrument scan patterns during helicopter flights (Simmons, Lees and Kimball, 1978). Eye point-of-regard measures have been used in experiments with automobile drivers to determine the effects of driving environment (Hughes and Cole, 1988), driving experience (Mourant, Rockwell and Rackoff, 1969), and types of road signs (Mori and Abdel-Halim, 1981). Since eye fixations fill up the available time, interpretation of data can be difficult and estimates of the usefulness of each fixation should be determined in low demand situations (Moray, 1986; Hughes, 1989).

Intrusiveness/acceptance. EOG electrodes are easy to attach and do not interfere with the operator's job performance. Operators readily adapt to wearing the electrodes. The EOG is a robust signal, which can be measured from ambulatory subjects using small operator worn recorders which provide continuous records. Eyeblinks do not require discrete stimulus events, only a temporal record of important events or segments. Eye point-of-regard measures may require either head-mounted equipment or off-the-head equipment. The head mounted equipment usually involves placing a front surface mirror or prism in front of one eye. Head mounted techniques can be used on ambulatory subjects while off-of-the-head techniques usually restrict the range of allowable head movements and are thus restricted to laboratory or simulator environments.

Reliability. The eyeblink articles in the literature have for the most part reported decreased blink rates and shorter duration blinks in high visual demand situations. Fatigue has been associated with more blinks and longer blink closures. Additional studies need to be performed in order to properly assess the reliability of eyeblink measurement techniques in operational situations (see Wilson and Eggemeier, 1991 for a review).

Applicability. Eyeblink measures have been recorded from operators during flight, simulated flight, and driving in addition to the numerous laboratory situations. These measures clearly have a high degree of face validity in terms of behavior and performance. Electrical eyeblink recording does not intrude onto the operators primary task and they are easily recorded from ambulatory subjects. Eye point-of-regard measurement requires equipment that can restrict movement. Blink measures seem to be applicable to situations of high visual demand or fatigue and not to situations of high auditory or cognitive demand.

Fluids

It is well established that most endocrine systems respond to perceived stress. The emotional impact on an individual is reflected in the person's neuroendocrine systems and the pituitary adrenal cortical axis system. The level of stress reactions to operational situations is dependent to some extent on our opportunity to exercise control over the situation (Vaernes, Knardahl, Roemsing, Aakvaag, Toender, Walter, and Ursin, 1988; Ursin, Mykletun, Toender, Vaernes, Relling, Isaksen, and Murison, 1984). A person who is able to regulate stimulus input is better suited for maintaining his psychological arousal and psychological involvement at an optimal level in a variety of situations than a person without this ability. But even when it is possible to regulate stimulus input, it has been shown that neural and hormonal activity change according to specific task demands and individual expectations across situations.

General activation responses can be evoked in emotionally unstable conditions such as operationally stressful environments. For instance, studies have shown that certain hormonal plasma levels are influenced in the initial phase of a multiple task situation, and later when coping strategies are established, another change in hormonal levels may be observed (Frankenhaeuser, 1978; Frankenhaeuser et al., 1980; Steptoe and Apels, 1989; Ursin, Baade and Levine, 1978).

The brain controls the autonomic nervous system and thereby influences the endocrine and the immunological reactions. This is revealed during general activation when almost the whole body is affected. Humans seem to have individual response patterns, probably due to both conditioning and genetic background. So far there is no evidence of response-specific conditioning of one hormone to other hormones. Though not substantiated, there may also be differences in the response profiles for males and females due to differences in overall balance of hormones between men and women. For example, Johansson, et al (1990) have reported differences in prolactin levels in men and women prior to and following psychological stress.

At the base of the hypothalamus situated immediately below the median eminence, is the pituitary gland (see figure 2). The pituitary gland is composed of two distinct lobes, the anterior and the posterior lobe. The anterior lobe secretes a number of trophic hormones, and the posterior lobe secretes antidiuretic hormone (ADH) under the influence of direct neural stimulation from the hypothalamus. The hormones secreted by the pituitary gland have controlling influence over all major areas of metabolism. The pituitary-adrenal system is sensitive to environmental changes which either elevate or suppress its activation level. The effect of unpredictable situations is sufficient to cause increases in the pituitary-adrenal activity.

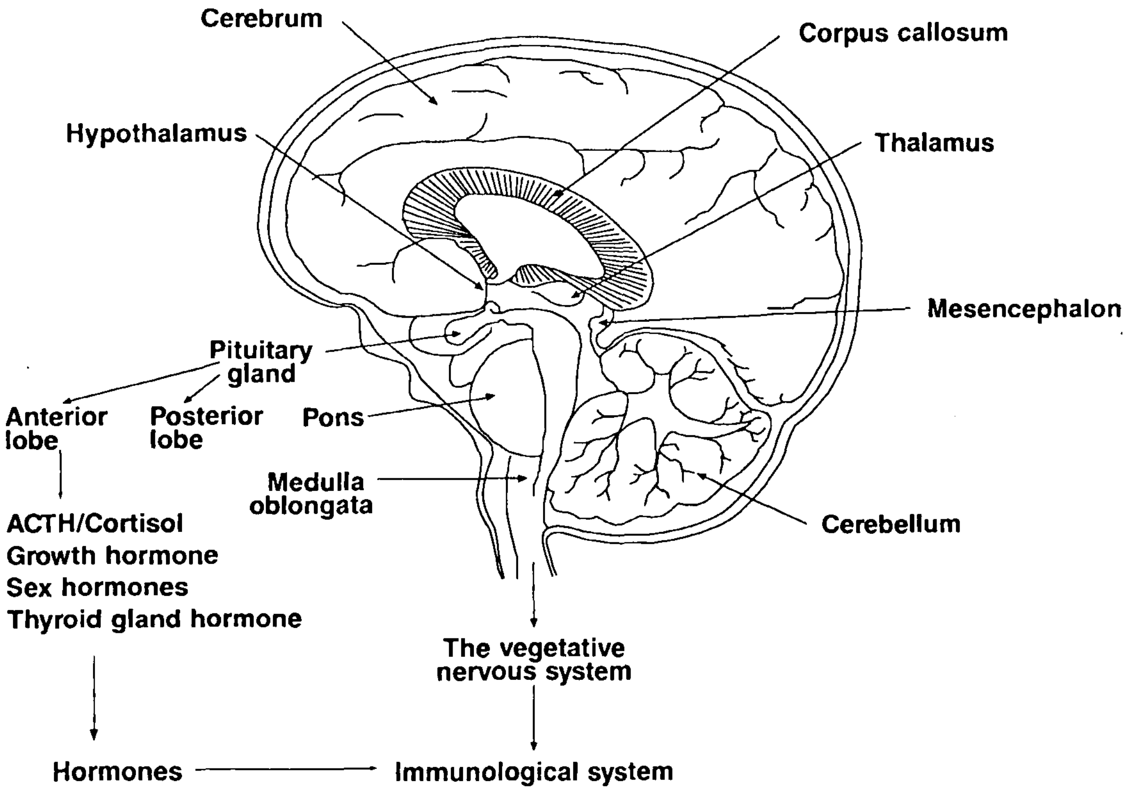

Figure 2. The Pituitary Gland is located below and shares rich connections with the hypothalamus of the brain. It has two distinct lobes, each having unique functions

ACTH (adreno-corticothropic hormone) is secreted from the anterior lobe and regulated by the hypothalamus. It affects the adrenal cortex and releases cortisol that affects the immune system. In the early years of stress research, ACTH was seen as the primary hormone responsive to stress and many investigations assessed ACTH as a dependent measure. However, later research has been performed to examine the influence of stress on catecholamines, prolactin (PRL), growth hormone, and testosterone. Several studies have demonstrated that prolactin is in fact released in response to stressful situations, but the functional importance of prolactin fluctuations remain obscure at this time. Significant correlations have been found between day-to-day changes in anxiety on one hand and cortisol and prolactin levels on the other. Also, a relationship has been established between rank position for dominance/aggression and prolactin and testosterone levels.

The sympathetic action of the brain is partially revealed in production of catecholamines and some prostaglandines. The catecholamines play a major role in mobilizing acute adaptive resources such as carbohydrate and fat metabolism, and prostaglandines have an influence on systemic circulation, sweat glands, eyes, and gut. Stress reactions can be detected in the hormonal secretion of catecholamines into the blood plasma.

Regulation of immune functions has been demonstrated from different sources. The nervous activity in such responses cannot be measured, but plasma hormonal levels are possible to monitor. Pituitary growth hormone and prolactin seem to reinforce immune functions while testosterone and cortisol (in addition to catecholamines) have immunosuppressive effects. Some of the plasma hormones, such as the catecholamines and cortisol, are related to immune parameters as well. Chronic high levels of catecholamines may moderate the immune response by a down-regulation of adrenoreceptors on lymphocytes or by interfering with leucocyte function.

Compared to hormonal measures, the immunoglobulins have been assumed to be stable over time, thus changes in the concentrations of immunoglobulins may reflect sustained activation in the organism. Concentrations of immunoglobulins (Ig) and their complement components may also serve as physiological stress indicators. The immunoglobulins and their complement components are involved in immunological processes essential to defend the organism against diseases. The immunoglobulins increase the ingestion and destruction of antigens while the complement components are involved in the mediation of immune reactions and are triggered by the interaction between the immunoglobulins and specific agents. The measurement of immunoglobulins requires sophisticated equipment and highly skilled technicians in laboratories specializing in blood analysis.

Methodology. When planning an experiment, one should keep several points in mind. First, when examining hormonal levels, be aware that the half-lives of prolactin and testosterone are short (20-30 minutes for PRL and 10-20 minutes for testosterone), which means a relatively quick return to normal values if the stimulus for increased secretion stops. In addition, the half-life of cortisol is about 60 minutes and the half-life of growth hormone is only 2 minutes. Second, most hormones evidence circadian rhythms which should be understood when planning research studies. When recording the level of a hormone, the zenith and the nadir of the circadian phase for that hormone should be known. When drawing a blood sample or receiving a urine or saliva sample from a person after a stressful or high workload situation, the exact sampling time must be registered, and the specimen obtained under the stressful circumstance should be compared to a specimen collected at the exact same time on another day when no stressful event has occurred (baseline value). Third, all hormones and related metabolic areas form a complex system which must be considered when the results of any variation are assayed (see figure 3). More detailed information on data collection and analysis can be found in Appendix D.

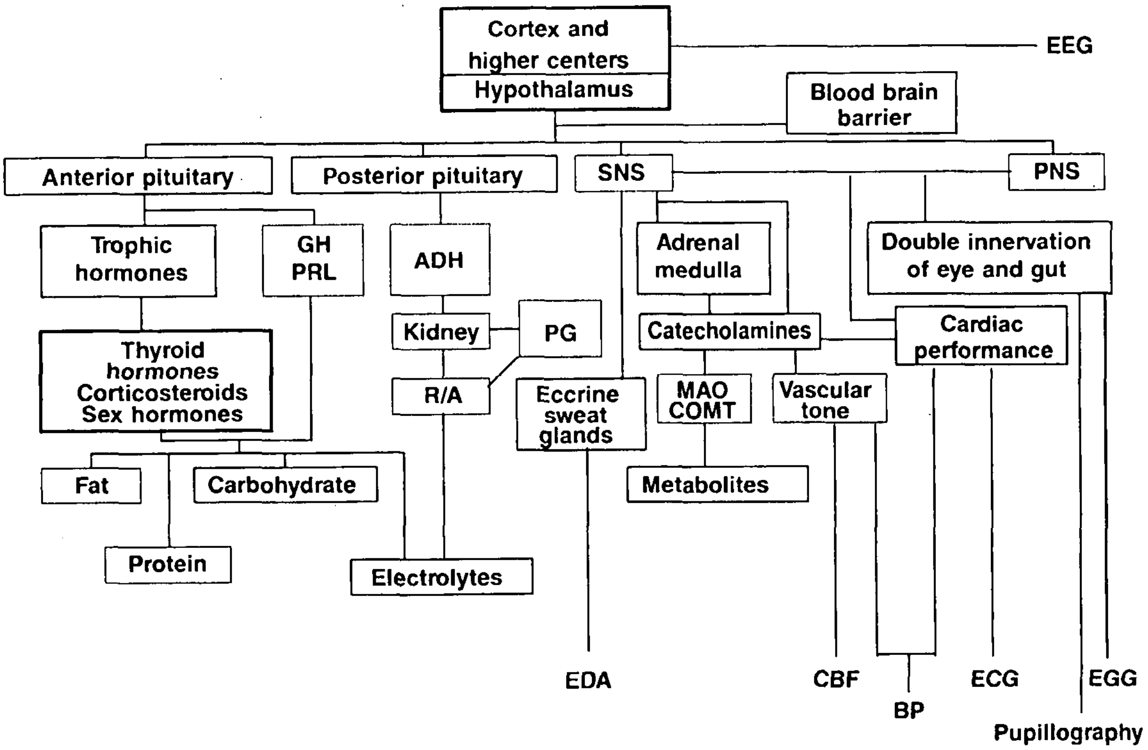

Figure 3. Areas of interest. SNS, Sympathetic nervous system; PSNS, parasympathetic nervous system; GH, growth hormone; PRL, prolactin; ADH, antidiuretic hormone; PG, prostaglandins; R/A, renin-angiotension; MAO, monoamine oxidase; COMT, catecholamine-O-meyhyl transferase; EDA, electrodermal activity; EEG, electroencephalogram; ECG, electrocardiogram; EGG, electrogastrogram.

Sensitivity and Diagnosticity. Prolactin, cortisol and testosterone are all sensitive to stress and high workload, and prolactin is sensitive to stress anticipation and anxiety. All have been used as stress indicators in several studies. Prolactin level is reduced if the subjects in the study have been subjected to physical exercise prior to the sampling time. For the assessment of hormonal reactions to stress and high workload, there are several hormonal analyses available. The choice of analysis that is best for a specific application should be dependent upon the biochemical expertise at hand. All of the above mentioned hormones have a circadian rhythm, and this should be taken into account when planning an investigation.

Intrusiveness/acceptance. Blood sampling may in itself represent a stressful situation to many subjects. Care should therefore be taken to thoroughly inform the participants about the reasons for the study and why the blood samples are required. The intrusiveness of the procedure may be reduced by using a butterfly catheter in situations where several blood samples are required (thus, a needle is inserted only once). Also, it is possible to perform some hormonal measurements on urine and saliva. Especially when working with aviators, research participants should be informed that information about their hormonal levels will not be used as grounding criteria. Gaining access to hormonal data and other additional information beyond what is available from regular medical examinations requires caution. It is imperative that participants in psychophysiological studies are assured that the results obtained will only be used for scientific purposes. However, if pathological results are revealed, at a minimum the subject should be informed so that he/she may decide which actions should be taken.

Reliability. The advantage of including hormonal data in a stress study is that, in addition to obtaining more data from the actual situation, hormonal levels can be sampled during the performance of actual operational or research tasks under standard or changing work loads. Accordingly, it is possible to register when and if the hormonal changes take place. Several studies have documented reliable hormonal and immunological changes during stressful situations (Ursin et al., 1978; Opstad and Aakvaag, 1983).

Applicability. Hormonal data can be collected across a wide array of tasks during which subjects are exposed to stressful circumstances. Thus, it is possible to measure the effects of stressors during operationally relevant performance. However, as mentioned earlier, hormonal data can be influenced by factors such as the participants' fears of having blood sampled or hesitations about exactly how the results of hormonal analyses may affect their flight status and careers. It is essential to minimize the stress of data collection by using the least invasive procedure possible and by thoroughly briefing the subjects prior to the study. Also, to ensure valid results, the researcher must 1) attend to proper storage and analyses of hormones with short half-lives, 2) be familiar with the circadian phase of hormonal responses, and 3) make provisions for the collection of appropriate baseline data. Finally, the investigator must be cautious in interpreting changes in certain substances because some stressful situations can result in fluid moving out of the plasma volume which results in an increase in hematocrit. When assaying substances such as lipids and proteins that do not readily filter in and out of capillaries, the plasma concentration of these substances can appear to increase although the real reason is a decrease in plasma volume.

Heart

As early as 1917, heart rates were recorded during flight (reported in Roscoe, 1992). Since then heart rate has been the most popular physiological variable used to monitor the state of human operators during flight. In addition to heart rate, measures of blood pressure and cardiac output have also been utilized. Additionally, the variability of the heart rhythm has been used as a measure of cardiac activity since some investigators feel that its magnitude is at least partially determined by cognitive factors such as workload (Grossman and Wientjes, 1986). The heart is innervated by both the sympathetic and the parasympathetic nervous systems whose activity is influenced by higher cortical centers. The sympathetic nervous system increases the firing rate of the heart's pacemaker and also modulates the constriction and dilation of the blood vessels. The parasympathetic nervous system inhibits the firing rate of the pacemaker cells via the vagal nerve and reduces heart rate. Both physical and mental activity are known to cause increased heart rates.

Methodology. The electrical sign of cardiac activity, the electrocardiogram (ECG), is characterized by the PQRST waveform. This is a relatively large signal and is therefore easy to detect. Further, since one is usually interested in only the heart rate or interbeat interval, only the R wave is of interest. Up to 12 leads are used to study cardiac activity; however in our context only one channel is required and electrodes should be placed to maximize the R wave amplitude. Due to these considerations, the actual placement of electrodes is not critical. However, if one is interested in measuring T wave amplitude, then a placement which maximizes this component should be used. Since physical activity and emotions influence heart rate, a resting baseline of at least 15 minutes should be provided to subjects prior to data collection (Hastrup, 1986; Jennings, Damarck, Stewart, Eddy and Johnson, 1992). This will permit them to return to baseline after the physical activity associated with getting to the laboratory and it will permit them to become accustomed to their new surroundings. These confounding effects should be considered when interpreting experimental results since their occurrence during testing can cause spurious data. Other factors influence cardiac activity such as respiration.

Heart rate variability requires continuous artifact free data, otherwise erroneous results can occur. Missed beats or short interbeat intervals caused by muscle activity can cause large errors in variability estimates (Mulder, 1992). Several techniques are available to detect R waves including amplitude thresholds and waveform recognition. Digital computers are typically used and sampling rates from 250 Hz to 1000 Hz are recommended. Heart rate variability can be estimated statistically, with regard to the respiratory cycle, with spectral analysis techniques and with special filtering procedures (Wilson, 1992a). Appendix E provides more information on recording and analysis procedures.

Crew members are sometimes concerned that abnormal ECG records will cause them to lose their flying status. This is an understandable concern. However, the computerized data analysis techniques typically used in psychophysiology are not designed to detect clinical abnormalities.

Sensitivity and Diagnosticity. The measurement of heart rate has been popular in the examination of operator state and mental workload because of the simplicity with which it can be recorded and analyzed. Numerous studies have found systematic relations between cognitive demands and heart rate in both laboratory and real world environments (see Kramer, 1991; Roscoe, 1992; Wilson and Eggemeier, 1991, for reviews). A number of studies have investigated the impact of various aspects of flight upon heart rate.

These include flying combat missions (Lewis et al, 1967), flying surface attack training missions (Comens, Reed and Mette, 1987; Wilson, 1993), flying aircraft test missions (Roscoe, 1980), landing at different airports (Nicholson, et al., 1970, Ruffell-Smith, 1987), gradient of landing approach (Roscoe, 1975), pilot vs co-pilot flying (Hart and Hauser, 1987; Kakimoto et al, 1988; Roscoe, 1978), high speed, low level flight (Lidderdale, 1987), and lead vs wing position (Wilson et al, 1987). Simulated flight studies have also reported increases in heart rate associated with increases in task difficulty (Lindholm and Cheatham, 1983; Wierwille and Connor, 1983; Opmeer and Krol, 1973). Heart rate has been used as a debriefing tool during aircraft test and evaluation (Rokicki, 1987; Roscoe and Ellis, 1990) and in the certification of commercial aircraft (Roscoe, 1987; Speyer, et al, 1988; Wainwright, 1988). These studies report increased heart rates with increased mental workload. Wilson and Fisher (1991) used cardiac and eye blink variables to correctly classify segments of flight for pilots and weapon systems officers for air-to-ground training missions. Similar effects have also been reported in automobile driving (Taggart et al, 1969; Helander, 1975; Lecret and Pottier, 1971), boat driving (Johnson, 1980), and radar operation (O'Hanlon and Beatty, 1977).

Heart rate variability has also been shown to be a sensitive measure in terms of evaluating task demands. Several studies have reported decreases in heart rate variability with increasing task demands. Specifically, it has been found that the mid-frequency band (the 0.10 Hz component) is sensitive to the amount of mental effort that has to be invested to meet the task demands (Mulder and Mulder, 1980, Mulder, 1992). Consequently, reductions in the 0.10 Hz component will only be evidenced in resource-limited tasks. Increases in task difficulty in data-limited tasks are not accompanied by a reduction in the 0.10 Hz component. The tasks evaluated have included simulated and actual flight (Opmeer and Krol, 1973; Lindholm and Cheatham, 1983; Lindqvist et al, 1983; Sekiguchi et al, 1979; Wilson, 1993). Opmeer and Krol (1973) reported that heart rate variability and respiration were sensitive to simulated flight task demands. Itoh, et al (1989) found heart rate variability in the 0.10 band to decrease during take off and landing when compared to cruise segments. Transient aircraft difficulties also produced decreased 0.10 Hz activity. Wilson (1993) found decreased mid- and high-frequency band activity during high demand segments of air-to-ground missions and during a ground based tracking task. Neither band could distinguish between flight segments nor between flight segments and the tracking task. Egelund (1982) reported changes in heart rate variability as a function of driving conditions and driver fatigue. Jorna and Mulder (1983) found differences in heart rate variability between experienced and inexperienced underwater divers. The high frequency band which reflects respiratory activity provides an index of the influence on the heart of the parasympathetic nervous system. This band has been reported to be sensitive to manipulations of cognitive workload (Porges and Byrne, 1992; Grossman, 1992). The T-wave amplitude of the ECG appears to reflect primarily sympathetic influence on the heart but there is a lack of consensus with regard to its utility (Furedy and Heslegrave, 1983).

Intrusiveness/acceptance. Since electrodes are easy to attach and to wear, heart rate qualifies as a nonintrusive measure. Also, because it can be measured continuously in ambulatory subjects, the operator can engage in a wide range of activities. Because discrete stimuli are not necessary for analysis, only a temporal label is needed to indicate at what time a particular activity started. Since heart rate variability is derived from measures of heart rate, no special data recording considerations are required, only additional analysis steps.

Reliability. Reliable effects of task demands on heart rate have been reported in numerous situations involving real world environments. Changes in the mid- and high-frequency components have only been found for relatively large differences in task difficulty. Some reports fail to find any advantage for heart rate variability indices over measures of simple HR alone (Wilson, 1993). Physical activity produces increases in heart rate and blood pressure independent of concurrent cognitive demands. Therefore, physical activity should be monitored and taken into consideration when interpreting the data. On the other hand, this makes cardiac activity appropriate as a measure of physical work. The relationship between the amount of physical effort and heart rate are well known and formulas have been developed to convert heart rate into an estimate of energy expended (Eastman Kodak, 1986). Heart rate can then be used as a measure of physical activity in situations such as aircraft load masters and equipment setup.

Applicability. Reliable and valid results have been found in a broad range of tasks, manipulations, and environments (besides standard laboratory situations). They include flight, simulated flight, automobile driving, and undersea diving. The recording of the ECG is very appropriate for ambulatory monitoring. However, ECG recordings may be contaminated by changes in the characteristics of the skin, movements, and muscle activity. It may also be confounded by body position or speech. Finally, large changes in respiration depth and frequency may not only affect the high-frequency heart rate variability band, but also the 0.10 Hz band. Thus, whenever possible, respiration should also be measured in conjunction with heart rate. The utility of heart rate variability in ambulatory studies will remain questionable until further confirmatory studies are reported. Since heart rate variability is known to decrease with aging, the age of the study population must be considered.

Muscles

The electromyographic (EMG) signal is the expression of the electrical activity associated with muscular contraction. The transmembranous action potential in a muscle fiber is characterized by a sequence of ion motions which subsequently polarize and depolarize the membrane. The origin and the propagation of the action potential are the basis of the electrical activity of the muscle, EMG representing its electrophysiological expression. Two techniques can be used to record electromyographic signals. 1) Electrodes may be inserted into the muscle (unit electromyography) for analysis of action potentials. Action potentials, recorded very close to muscle fibers, are a true reflection of differences in transmembranous potential. This recording technique is most often used in medical examinations with diagnostic purposes. 2) Surface electrodes placed on the skin (overall electromyography) produce signals which represent accumulation of underlying unit potentials. This technique is most commonly used for applied physiology investigations. Comments and recommendations in this report concern the recording of EMG activity using surface electrodes.

Methodology. Surface electrode placement is commonly determined through an anatomical analysis of the muscles to be studied. In each subject, manual palpation permits the best placement of the electrodes over the belly of the muscle, near its motor point. Pairs of silver/silver chloride (Ag/AgCl) electrodes are commonly used, 4-7 mm in diameter, and spaced 10-20 mm apart. The skin is cleaned with 33% ether, 33% acetone, and 33% ethyl alcohol, then carefully prepared by abrasion with sand paper. The two active surface electrodes are applied longitudinally over the belly of the muscle, parallel to the fiber axis. Electrode resistance should be below 5-7 Kohm. A third electrode is placed over a spinous process of vertebra and is connected to the ground of the isolation amplifier.

The surface EMG signals are amplified using a multi-channel system. After amplification the signals are bandpass filtered (upper filter frequency commonly accepted is set to 1 KHz, and the lower to 10 Hz). The signals from each channel may be verified using an oscilloscope, and then passed to a frequency modulated tape recorder. Current systems permit the digitization and storage of the signals by computers. Detailed information about EMG collection and analysis can be found in Appendix F.

Integration of the EMG signals is commonly used to study the motor responses of different muscle groups during specific movements. After amplification or tape recording, the EMG signals are full-wave rectified, then integrated with a time constant ranging between 0.5-2 s. The changes observed in the integrated EMG signals are used as the measure of muscle activity.

The power frequency spectrum of EMG signals are also commonly used to quantify the muscular events occurring with fatigue. The Fast Fourier Transformation (FFT) is used to convert the recorded time domain data to frequency-based data (power frequency spectrum). Each time domain record is divided into a selected number of segments (10 to 20). The frequency content of each segment is calculated by the FFT. These analyses are performed using a computer system, and the final result of these calculations is a number of EMG parameters including the mean power frequency (MPF).

Sensitivity and Diagnosticity. A number of time domain and/or frequency domain parameters from either voluntary or electrically elicited surface myoelectric signals carry information useful to estimate muscle properties and to quantify muscle performance. The main issues investigated by means of surface myoelectric signal processing are the following: 1) the relationship between myoelectric signal amplitude and force during isometric or dynamic contractions; 2) the relationship between spectral parameters, muscle fiber conduction velocity, tissue filtering function and muscle fatigue; 3) non-invasive fiber typing and muscle characterization.

It is now well established that the electromyogram amplitude is a consistent and sensitive measure of motor unit recruitment. Several studies have clearly shown the linear relationship existing between the force generated and the mean signal recorded either during isometric exercise (Lippold, 1952), or during contractions with constant velocity (Bigland and Lippold, 1954). Linear relationships between contraction strength and integrated signals have been found under many experimental conditions (Lippold, 1952; DeVries, 1968). The form of this relationship remains a matter for discussion since exponential and quadratic relationships have been shown. Thus, whatever the form of the relationship, the integrated EMG signals increase with muscle strength. Pilot studies have proposed analysis models providing the ability to predict the potential muscle capability of an individual. These methods would be helpful in situations such as employee placement in aerospace ergonomics.

Since the work of Piper (1912), the frequency components of the surface electromyogram have been known to decrease during sustained contraction. It has been found that this shift in frequency toward the low end with fatigue, was concomitant with an increase in amplitude of the signal. These two phenomena are related and it has been shown that during sustained contraction, the low-frequency components of the signal increase (Kadefors et al., 1968). This shift in frequency is due to an increase in the power of lower frequency components, and a decrease in the power of higher frequencies. It induces an increase in signal energy transmitted through the body tissue (De Luca, 1984). Thus, the power frequency spectrum analysis of the electromyogram signal appears to be an accurate method to detect muscular fatigue.

Several studies have reported a relationship between the proportion of fiber types of a muscle, and the mean power frequency of the electromyogram. A close linear correlation between the mean power frequency and the fiber type proportion of the vastus lateralis muscle has been found in the human (Gerdle et al. 1988). Thus, it has been suggested that the analysis of the characteristics of the electromyogram during sustained submaximal contraction might be used as a non-invasive method for determination of the fiber type proportion.

Intrusiveness/acceptance. Surface detection of myoelectric signals offers a number of advantages over needle detection. Electrodes can be applied without discomfort, medical supervision, and risks of infection. Subject acceptance of the surface EMG is very high. Moreover, the repeatability of measurements is higher, and long term monitoring far easier than with needles.

Reliability. The variability of the electromyogram spectral measures strongly contributes to its sensitivity. The variability of these measures has been recently reviewed (Roy and De Luca, 1989). The repeatability of the method has been studied with different time durations between tests, different force levels of contraction, different muscle groups, and different individuals. The results show that the variability of the electromyogram spectrum analysis was greater between experiments than within an experiment. Moreover, it is apparent that the intra-experiment variability increased with the force level of the contraction. The repeatability for long duration contractions was also studied, and showed a consistent similarity of the median-frequency variations throughout the duration of the contractions. The repeatability of the median frequency was tested on different days; the results demonstrated a reliable repeatability of the median frequency on the same day and different days. The higher variability observed for measurements on different days was likely attributable to the high sensitivity to electrode location. The reliability of the measure of the mean power frequency has been tested for different methods (Roy and De Luca, 1989). The estimates of the mean power frequency using digital computation when compared with a reference method have been shown to be virtually equal.

Applicability. The study of changes in the EMG signal is a noninvasive analytical tool which yields reproducible results. It can be used in aviation physiology to answer various questions. The EMG analysis can be of great usefulness in: 1) the assessment of the strength generated by a given muscle, when it is materially impossible to measure this strength directly; 2) the study of the motor strategy and kinetics of recruitment of muscle groups in a given experimental situation; and/or 3) the study of EMG parameters of muscular fatigue (i.e. peripheral fatigue which differs from processes of general or central fatigue). The definition of the experimental framework also determines the type of analysis that will be conducted on the EMG recording. The motor strategy will be analyzed by integration of the EMG recordings obtained for different muscle groups being studied, whereas the EMG parameters correlated with fatigue will be studied by an analysis of the power spectrum. The recorded activity could be correlated with other psychophysiological activity such as heart rate and EEG.

Respiratory

Respiratory measures provide valuable information in applied situations that may be used for quite different purposes. Respiration has been recorded for the following goals: 1) to evaluate the effects of work demands; 2) to evaluate the effects of environmental stressors, such as G-forces and vestibular stimulation; 3) to detect hyperventilation, signalling overreactivity caused by danger or threat; and 4) to obtain an approximation of energy expenditure.

Measurement of respiration is still rather uncommon in psychophysiology. One reason is that the breathing pattern is quite complex. It may vary both in volume and in time. Most noninvasive techniques only provide an assessment of rate and not of volume parameters. Respiration rate, however, is rather insensitive to workload and stress, and does not provide physiologically meaningful information. Therefore, the measurement of respiration can only be successful if techniques are used that provide both time and volume parameters. Recently, such a technique has become available that is unobtrusive and easy to apply (Grossman, 1992; Wientjes, 1992a, 1992b).

Methodology. Ventilatory adaptation to changes in metabolic demands is primarily determined by the response of the respiratory center and the peripheral chemoreceptors to increases in the CO_2 and hydrogen-ion concentrations in the blood. Because increased ventilation, in turn, results in an increase in the rate of elimination of CO_2 via the lungs, arterial CO_2 and Ph levels are normally kept within a very narrow range. Cortical and other neural factors, on the other hand, may often override metabolic respiratory control mechanisms. These influences are responsible for respiratory changes during, for example, speech, emotions, and mental effort (Bass and Gardner, 1985). Due to these factors, aversive stimuli and psychological stress may sometimes induce exaggerated ventilatory activity (hyperventilation), which causes more CO_2 to be eliminated from the body than is produced by metabolic processes. As a consequence, arterial pCO_2 levels decrease below normal values (hypocapnia).

The breathing cycle is characterized by the following parameters: duration of inspiration (Ti), duration of expiration (Te), the total cycle duration (Ttot), its inverse respiratory rate (RR), and tidal volume (VT; i.e., the volume that is displaced during one breath). There is considerable evidence that the breathing cycle is centrally controlled by two mechanisms: a drive mechanism, governing the firing rate of the inspiratory neurons, and a timing mechanism, switching these inspiratory neurons on and off. The drive mechanism is primarily under control of chemoreceptor input. The timing mechanism is controlled by a central rhythm generator. The drive mechanism is indexed by the inspiratory flow rate (VT/Ti) and the timing mechanism by the duty cycle time (Ti/Ttot). The minute volume (MV), the total volume ventilated per minute (VT * RR), is equal to the product of the two indexes (VT/Ti * Ti/Ttot)(Milic-Emili, Whitelaw and Grassino, 1981). Appendix G contains more detail on data collection and analysis procedures.

Sensitivity and Diagnosticity. Over the last three decades, a number of studies have assessed respiratory changes during the performance of effort-demanding tasks or stressful challenges. Although the measures and the techniques employed vary across studies, the findings display a remarkably similar pattern. Compared to baseline conditions, mental effort and mild stress are generally associated with an increase in RR, a decrease in VT, and an increase in MV (e.g., Benson, Huddleston and Rolfe, 1965; Carroll, Turner and Hellawell, 1986; Carroll, Turner and Rogers, 1987; Kagan and Rosman, 1964; Langer et al., 1986; Rousselle, Blascovich and Kelsey, 1989; Sims et al., 1988; Svebak, 1982; Svebak, Storfjell and Dalen, 1982;

Turner, Carroll and Courtney, 1983; Turner and Carroll, 1985; Wientjes, 1992a; Wientjes, 1992b). However, a few studies have not found a decrease in VT, but rather no change, or even an increase in VT (Allen and Crowell, 1989; Allen, Sherwood and Obrist, 1986; Benson, Huddleston and Rolfe, 1965; Wientjes, 1992a; Wientjes, 1992b). A possible explanation is that VT decreases with moderate demands, but increases again with extreme demands (Benson, Huddleston and Rolfe, 1965; Wientjes, 1992a; Wientjes, 1992b), or with painful passive coping stress (Allen and Crowell, 1989; Allen, Sherwood and Obrist, 1986).

A few studies did not find RR increases with greater mental workload (Benson, Huddleston and Rolfe, 1965; Cohen et al., 1975; Wientjes, 1992a; Wientjes, 1992b). The interpretation of the findings concerning the influence on task demands on RR is often difficult because the results may have been confounded by other factors than mental load, such as vocalization, motor activity, threatening context, aversiveness, etc. (Allen and Crowell, 1989; Allen, Sherwood and Obrist, 1986; Carroll, Turner and Rogers, 1987; Kagan and Rosman, 1964; Svebak, 1982; Svebak, Storfjell and Dalen, 1982; Turner and Carroll, 1985).

Recent evidence strongly suggests that the drive mechanism is highly sensitive to work demands. In a study that assessed the influence of different incentives and demands upon performance in a memory comparison task, inspiratory flow rate (VT/Ti) discriminated reliably between task conditions (Wientjes, 1992a; Wientjes, 1992b). This implies that a greater workload was associated with a stronger central inspiratory drive. In contrast, the index of the timing mechanism of respiratory control, respiratory duty cycle (Ti/Ttot), did not change consistently with regard to task condition. Only in the most demanding task period was a small increase in Ti/Ttot observed.

In summary, the sensitivity of respiration is greatly dependent upon the choice of parameters. Merely employing time parameters such as RR yields results that are not sensitive to task demands and stress. Hence, contrary to traditional opinion in the literature, RR is not a reliable index of mental effort or stress (Cohen et al., 1975; see also Wilson and Eggemeier, 1991).

Although only a small number of the studies that were discussed has actually monitored end-tidal pCO_2 levels (Allen, Sherwood and Obrist, 1986; Benson, Huddleston and Rolfe, 1965; Langer et al., 1985), they are quite consistent in demonstrating that active coping (i.e., being actively engaged in the performance of demanding mental tasks) is not associated with hyperventilation and hypocapnia. Therefore, the ventilatory alterations that are induced by these tasks are most likely to reflect changes in metabolic activity, probably associated with changes in motor activity (e.g., due to response execution, speech or muscle tension). In contrast to these homeostatic respiratory responses, certain aversive conditions may induce hyperventilation (Dudley, 1969; Freeman, Conway and Nixon, 1986; Suess et al., 1980). For instance, pain (or cold), such as that induced in cold pressor tasks, is known to produce hyperventilation in a subset of subjects (Allen, Sherwood and Obrist, 1986). Hyperventilation may importantly influence the subjective, as well as the objective state of the operator: it produces not only various adverse somatic symptoms, but may also cause a reduction in cerebral and myocardial perfusion and O_2 delivery (Grossman and Wientjes, 1989), thereby potentially reducing cognitive functioning.

Intrusiveness/acceptance. Intrusive respiratory measurement techniques (e.g., pneumotachography) provide very accurate assessment of the time and volume parameters of the respiratory pattern. They greatly restrict, however, normal activities, and they employ equipment that adds dead space and resistance to breathing, which may strongly influence spontaneous breathing (Askanazi et al., 1980; Gilbert et al., 1972). Traditional noninvasive techniques (e.g., strain gauges, thermistors) are inadequate because they do not provide accurate information concerning volume. Recently, a technique has become available that provides quantitative estimation of both time and volume components of respiration without interference with spontaneous breathing. This technique is based on the separate measurement of motions of the rib cage and the abdomen by means of strain gauges, or inductive respiratory plethysmography (Chadha et al., 1982; Morel, Forster and Suter, 1983). Volume estimation is based upon the assumption that the volume of air that is displaced during each breath is proportional to the changes of the rib cage and abdominal compartments. Because the contribution of both compartments to the total volume may be different between individuals, a calibration procedure is needed for each individual subject (Chadha et al., 1982; Gribbin, 1983; Morel, Forster and Suter, 1983). After calibration, the sum of the rib cage and abdominal circumference changes provide an adequate estimate of respiratory volume. Slipping of the bands (causing measurement inaccuracies) can be prevented by an elastic vest put over the chest. Movement artifacts, i.e., during ambulatory monitoring, can be reduced by employing a bandpass filter that attenuates frequencies that are likely to be associated with movement (e.g., Anderson and Frank, 1990).

Alveolar pCO_2 is considered to be a valid approximation of arterial pCO_2 (Gardner, Meah and Bass, 1986). Alveolar pCO_2 can be measured by sampling the expired air at the end of expiration (end-tidal pCO_2). The most commonly used equipment for measurement of end-tidal pCO_2 is the infrared gas analyzer or capnograph, that may interfere with the ongoing activities in applied situations. Alternatively, arterial pCO_2 may be measured transcutaneously by means of a heated electrochemical sensor (Pilsbury and Hibbert, 1987). The main problem with this method is the time lag of several minutes between a change in arterial pCO_2 and the response of the sensor. This may not be a serious problem, however, with long-term measurements. Notwithstanding its limitations, transcutaneous pCO_2 measurement may be very useful for ambulatory monitoring of PCO_2 during applied studies (Hibbert and Pilsbury, 1988).

Reliability. Many researchers who have studied respiration tend to treat this measure as a straightforward homeostatic function which is sensitive to the effects of any stimulus which would affect metabolic rate (such as exercise or fear-producing stimuli). In this regard, respiration measures are highly reliable both within subjects and between subjects. However, there are often subtle effects of psychological factors which may create transient changes in respiration (Lorig and Schwartz, 1990), and these effects logically would be more variable depending on the makeup of individual subjects.

Applicability. The few applied studies that have employed respiratory measures have yielded potentially important results. For example, in an extensive recent study by Harding (1987), respiration and end-tidal pCO_2 were measured among jet fighter pilots during different flight segments in a high-performance aircraft. The results show that RR, peak inspiratory flow, and MV were increased during all phases of routine flight, and that marked elevations of respiratory activity were found during maneuvering phases that were very demanding. Mild but sustained hyperventilation occurred during flight phases that involved high G-maneuvers; this was probably partially due to the active methods that were applied by the pilots to increase their tolerance to +G acceleration ('straining'). However, the end-tidal pCO_2 values were, generally, well above the range that may be considered dangerous. It should be noted, however, that these flights were not regarded to be stressful. It has frequently been suggested that stress during flight might lead to substantial reductions in pCO_2 with potentially dangerous consequences (Gibson, 1979; 1984). One of the possible detrimental consequences of hyperventilation is its pronounced effect upon psychomotor performance (see Gibson, 1978).

Another field of application is exposure to vestibular stimulation. In one study assessing subjective and physiological responses to different conditions on board a mine-hunter, high within-individual correlations were found between degree of motion sickness, state anxiety, and end-tidal pCO_2 decrease (Bles et al., 1988). These results suggest that hyperventilation may serve as a useful index of the impact of an aversive stressor upon the individual.

Sleep Polygraphy

Although the reason we sleep is still unknown, we have many investigations which indicate that sleep is necessary (Babkoff, Genser, Sing, Thorne and Hegge, 1985; Bonnet, 1987, 1991; Carskadon and Dement, 1981). It is generally accepted that there are two kinds of sleep--REM and nREM (pronounced nonREM) (Dement, 1978). The discovery of REM sleep in the early 1950's was the major breakthrough in sleep research. After the two types of sleep were identified, researchers discovered the cycle of sleep which occurs over the night. Although the number of minutes in each stage vary among individuals, it is recognized that normal sleep begins at stage 1, progresses through stage 4 and REM, returns to stage 2, progresses back into stages 3 and 4, returns to REM, and then alternates between stages 2 and REM for the remainder of the night.

The circadian rhythmicity of sleep was also investigated. Kleitman and Richardson (cited in Dement, 1978) charted normal human wake and sleep times without external cues. Since that time, there have been numerous studies which have indicated both the cyclical nature of sleep over the night as well as the circadian rhythmicity of sleep and wakefulness (Feinberg and Floyd, 1979; Taub and Berger, 1973; Tune, 1969).

Sleep polygraphy is used in both laboratory and clinical settings. It is a highly standardized and often described method in which sleep is recorded and scored into stages according to Rechtschaffen and Kales (1968). Sleep staging requires a minimum of one EEG derivation, two EOG derivations, and one EMG derivation. Usually more than these four channels are recorded to obtain redundant information which will diminish the possibility of data loss due to electrode problems.

Methodology. The EEG signals obtained for sleep polygraphy are similar to those obtained for a resting EEG. The electrodes, usually silver-silver chloride, or gold, are attached to the scalp with collodion before the person retires for the night. Usually one or two EEG electrodes are attached, along with a mastoid reference, two EOG electrodes, and two EMG electrodes. Amplification of the signals is accomplished via standard polygraph amplifiers. The signals are recorded on paper, usually at a speed of 10mm/sec, or by a computerized system configured for sleep polygraphy. The data are usually stored on paper or disk for future analysis. Using standard guidelines, the stages of sleep are determined by scoring each epoch (20-30 second period) throughout the record. The data are scored for stages 1 through 4, REM, awake, and movement for each epoch throughout the sleep record. Most data are scored visually following standardized criteria set for by Rechtschaffen and Kales (1968). New computer systems have been developed to score the data using mathematical functions, but at present, there is no widely accepted automatic scoring procedure which can take the place of a human sleep scorer. Appendix I contains information on the procedures commonly used for collecting and analyzing sleep data.

Sensitivity and Diagnosticity. Sensitivity and validity of sleep polygraphies may be enhanced by extending the evaluation beyond standard procedures. In general, power spectral density of EEG recordings parallels sleep stages, becoming maximal during slow wave sleep (Akerstedt and Gillberg, 1986). The evaluation of power densities reveals a close relationship to existing models for sleep regulation (Daan et al. 1984). It is generally accepted that the diagnosticity of sleep polygraphy is high for detecting changes in sleep.

Standard sleep records have been used for years to detect changes in sleep attributable to drugs (Beary, Lacey, Crutchfield and Bhat, 1984; Mendelson, Martin, Stephens, Giesen and James, 1988; Roth, Hartse, Saab, Piccione and Kramer, 1980; Spinweber and Johnson, 1982; Wheatly, 1981), environmental manipulations (Caldwell, Thornton, Pearson and Bradley, 1992; Johnson, Spinweber, Webb and Muzet, 1987; Webb and Agnew, 1964), and physiological functions (Lubin, Hord, Tracy and Johnson, 1976; Stones, 1977).

Additionally, sleep studies have been used to assess a variety of clinical complaints, from insomnia to impotence. Studies over many years have determined what is considered "normal" sleep (Carskadon and Dement, 1989; Dement, 1978), and many clinical recordings have determined the causes of a variety of complaints, to include excessive daytime sleepiness, insomnia, and impotence (Hauri, 1982; Roffwarg, 1979).

Intrusiveness/acceptance. To record sleep polygraphies, a minimum of six electrodes must be applied after placement sites are thoroughly cleaned. This application procedure can be time consuming and mildly aversive to some individuals. Also, the actual sleep evaluation generally takes more than one night in the laboratory. Usually, a subject is required to spend one or more adaptation nights in the laboratory to get accustomed to the electrode hook-up and the surroundings prior to the actual data-collection period. In addition, if cameras are to be used to monitor the subject while he/she is sleeping, some individuals will object to this loss of privacy.

Reliability. It is generally accepted that sleep polygraphy is a reliable measure of sleep. After years of research, a "normal" pattern of sleep has been determined (Carskadon and Dement, 1989). With the construction of a standardized scoring system in 1968, the ability of different laboratories to compare sleep studies has increased, thereby expanding the field of sleep research.

Applicability. Particularly in field studies, the cost to record sleep polygraphies may be too high and the practical difficulties too large. In this case, the use of body activity measurements and sleep questionnaires should be considered (Buck et al., 1989). Activity monitoring can provide estimates of sleep onset, sleep quality (to a degree), and sleep duration, but information about sleep structure (architecture) is available only from sleep polygraph data.

CHAPTER 4
SYNTHESIS AND SPECIAL CONSIDERATIONS

Testing Human Subjects

One of the primary factors which must be considered at the outset of any experiment relates to the subjects who will be recruited and tested. In many instances subjects of studies in aerospace medicine will be professionals, e.g. pilots, air traffic controllers or flight attendants. Usually they do not receive extra pay for taking part in investigations, but they often participate voluntarily and consider it to be part of their job duties. The study often will be conducted in an environment in which the peculiarities of the subject's job position and possible job conflicts must not be ignored. Furthermore, it is reasonable to assume that subjects will expect some benefits for their health or job situation from an experiment in which they serve as a subject, and the investigator should indicate what the benefits and risks of participation are at the outset.

Often subjects will show aversion to psychological and medical studies which may originate from unpleasant past experiences or simply from the fact that pilots have to submit to regular medical examinations in order to ensure fitness for their jobs. Thus, volunteers may feel that any psychological or medical examination could in principle influence their professional careers. Consequently, psychophysiological measurements should be carefully considered when dealing with subjects in their work environments.

When planning a research study, the investigator should seek approval from the local ethics board (if available) before starting the investigation. To avoid problems in a possibly complicated work environment during the study, a positive and open atmosphere should be created. Different parties such as military commands, airline management, pilot unions, and flight surgeons should be involved on an informational basis if appropriate. Scientific jargon should be avoided when briefing personnel about the purposes and procedures involved in an investigation, and the researcher should encourage open and free discussions of any questions participants may have. The subjects may feel as though they are being used merely for scientific purposes and that the investigator has little concern for them individually. Therefore, at the beginning and the end of the study, the investigator must be prepared to justify all measurements and procedures. If possible, the subjects should be briefed on the results of the study and what these results may mean to them and the aviation community.

As with other medical examinations, professional discretion is most important. Measurements may be conducted that may have severe consequences for the subject's career if they are the sort of measures normally collected during routine medical checks (i.e., ECG evaluations). Therefore, the data must be handled with care and confidentiality. Usually it is helpful to avoid associating the names of subjects with particular data points. Instead, an anonymous code can be used to label the data.

Before results are reported to the scientific community, subjects should be informed and a possibility for a personal discussion should be provided. The availability of consultations, confidentiality issues, risks, benefits, and other factors of interest about the study should be presented to the subject in writing prior to his/her participation whenever possible.

Laboratory Safety

The safety of laboratory workers and subjects alike should be a primary consideration in the design and implementation of any research project. Even psychophysiological measures, such as EEG and EMG which are comparatively noninvasive, involve risks to subjects and experimenters which should be minimized through careful attention to safe procedures. Since electrical recordings normally involve creating low resistance pathways to the skin, extreme caution should be used to avoid the chance of accidental shocks through short circuits or lightning. For this purpose, many acquisition systems use a stage of optical coupling to isolate the subject from the electrical system powering the amplifiers and signal conditioners. Careful separation of the neutral and ground wires is also required for EEG and most other medical equipment.

In addition, the risk of serious spread of infection during application of electrodes is not insubstantial, particularly with the HIV and other viruses present in the general population. Proper cleaning of electrodes using detergent, disinfecting solutions whose concentration is carefully monitored, and safe waste disposal procedures are essential. Use of precautions by technicians during routine application and testing, including rubber gloves, safety glasses and face masks, should be carefully considered by investigators during the design of the research protocol. Procedures for other psychophysiological measures, particularly those involving collection and handling of body fluids, should be equally carefully thought out beforehand to avoid inadvertent ill effects to all of those involved in the research (Putnam, Johnson and Roth, 1992). Finally, in studies involving flight or flight simulation, health and injury risks involved must be carefully weighed against potential benefits of the research in formulating the research plan.

Ethical Considerations

There is increasing public concern about the dignity and other feelings of subjects which is reflected in increased scrutiny of ethical considerations vis a vis research subjects. Ethical considerations may involve effects of the research on cultural and/or institutional perceptions, customs, and requirements, meaning that the design of an experimental protocol often requires professional consideration and thoughts of the institutional ramifications of the research.

In most countries, safety and ethical factors are the concern of institutional human subject research review boards, which must approve any research plan before the research is allowed to be carried out. These boards may have members from the local clergy and legal profession, as well as medical specialists. Accordingly, their deliberations may not weigh the technical and scientific factors leading to a particular protocol as carefully as the authors of the protocol may wish. The investigators, therefore, must provide the board with a carefully constructed account of the rationale for each feature of the proposed protocol. Naturally, even when scientific issues are agreed on by all, there may be differences of opinion as to what constitutes questionable invasion of privacy, insupportable humiliation, or unacceptable health risks.

Even when no other disagreement exists between the ethics review board and investigators, institutional regulations may artificially limit what may be investigated. For example, if pilots reporting any loss of consciousness during flight are permanently barred from further flying by longstanding regulations, it may be considered unethical to investigate loss of consciousness during high-G maneuvers using psychophysiological measurements even when the object of the research is improved pilot safety. Research with flight crews often carries this problem with regard to the certification of their status for flight. Aviators can be grounded on the basis of abnormal findings from ECG and EEG tests that are used to determine their health status. Crew members are aware of this and often are concerned about the collection of these types of data in a research project. They may feel that this exposes them to unwanted scrutiny and may feel this is a threat to their flight certification and continued ability to fly. This is certainly a risk factor and the level of the risk depends, to a certain extent, on the medical training of the research staff and the participation of flight surgeons and physicians in the research study since many scientists and technicians do not have clinical training. If an individual has a medical problem it should be called to their attention. The legal requirements for involving other medical personnel varies from country to country as do the regulations with regard to protecting the identity of research subjects. Currently, ECG and EEG data are often analyzed automatically by computers and the raw data are not seen by the investigators. Furthermore, electrode positioning in many research studies is different from the standardized placements used in clinical settings which may make clinical interpretation of the data difficult.

Since ethical judgements are bound up with regulations, cultural and institutional perceptions, and the expertise of the investigating team, the investigators must interact closely with local authorities to determine which protocols are likely to be scientifically fruitful and free of serious ethical problems.

Research Strategies

One of the most important decisions to make while setting up a research plan, is to determine whether the experiment will be done in the laboratory, in a simulator, or in the field. In the case of simulator study, there is a choice between part task simulation versus complete flight simulation; however, the costs (time, personnel, programming and apparatus) are larger the more complex the simulation. A more complex or complete simulation, with high face validity, is not necessarily better than a part-task simulation. Many aspects of the tasks and the influence of stressors (noise, vibration, sleep loss, etc.) may very well be simulated or examined with laboratory tasks as long as these tasks bear sufficient relevance to the actual task in the field. The choice to be made largely depends on the questions to be answered and the objectives of the research planned.

In this respect the following issues should be considered when making a decision about whether to conduct in-flight, simulator, or laboratory investigations:

1. When there are ethical or safety considerations, technical limitations, financial or organizational constraints, experimental investigations during actual operations (i.e., in-flight or in the field) may not be possible.

2. If long duration exposure to a stressor or intervention is to be studied, often the laboratory environment is the only one where a valid study can be performed. However, even in the laboratory, most research concentrates on short-term rather than long-term effects.

3. Conducting studies in the laboratory or in a simulator often opens the possibility that students and other persons can be used in investigations rather than aviators (who may not have the time). The use of more readily available personnel can save both time and money. However, one must be aware that differences between laboratory subjects and aviators can cause significant differences in the way tasks are performed and the way subjects may respond to these tasks.

4. In some situations professionals may have to be used because of the extensive selection and training required. This could be the case in air traffic control studies where the selection and training of laboratory personnel or students is prohibitive.

5. If, however, the tasks or missions to be studied are so difficult that only experienced and professional subjects can be used, an actual field study may be the only alternative. Unfortunately, professional personnel may tend to be biased in investigations where new procedures or equipment are being evaluated.

6. A clear advantage of both laboratory and simulator studies is that it is much easier to manipulate the variables of interest and, more importantly, to control variables which may confound the results.

7. Since the laboratory and simulators are "not the real world," field studies with actual pilots or air crew should be planned. There are sufficient differences between these environments and the subjects' attitudes towards them that it may be necessary to conduct flight tests to examine applicability of the laboratory or simulator data to the actual work environment.

Even in cases where it is clear that a study can be conducted in the actual aircraft or in another operational environment, it is essential that preliminary or pilot studies be conducted in the laboratory prior to initiating the field investigation. This is necessary to find out what the critical conditions are and which dependent variables should be collected. Also, it provides the opportunity to develop data recording procedures. Obviously it is more cost effective and efficient to do such preliminary evaluations in the laboratory rather than in the actual working situation.

In general, it is always better to start investigating a particular problem (whether in the field or in the lab) with inexpensive and easy methods, such as questionnaires, face-to-face interviews with operators, and/or observations by trained experimenters. These data can then be analyzed before initiating larger experiments which will include physiological methods that are typically more difficult to obtain. In fact, it should be noted that most studies in aviation research that have used psychophysiological methods have been exploratory, with only a few validating studies, and scarcely any applied studies.

Problems and Paradigms

Psychophysiological data, as is the case with other types of data, has special problems that must be understood so that appropriate corrective measures can be used where necessary. For example, individuals are known to show unique response profiles in terms of the way their various physiological systems respond to stressors. Some individuals will respond with large changes in a physiological variable, such as heart rate, while other subjects will respond with small changes to the same situation. The use of these raw data biases the statistics toward the subjects with the large changes. Using percent of change from a baseline condition may equate the changes from the subjects and give a more representative estimate of the effects of the stressor for the larger population. The distribution of some forms of psychophysiological data is skewed and therefore does not meet the normal distribution requirements of parametric statistical tests. For example, a log transformation is often recommended on FFTs of EEG data to normalize the distribution so that standard parametric statistical tests may be used with less concern about violating the assumptions of these tests. The references listed in this Advisory Report for each measure and the recommended general references listed at the end of the report should be consulted for guidelines. Besides these concerns there are general statistical design issues that must be addressed. It is essential that any project be designed so that conclusions can be drawn based upon the data. While this seems like a simple task, it is usually not a trivial matter. Consultation with a statistician is recommended. Further, since statisticians are usually not experts in psychophysiological measures, it is recommended that a psychophysiologist be consulted to identify issues that should be addressed. The accompanying Register of Psychophysiologists can be used to locate people who have experience with the various psychophysiological measures.

One issue that will be central to decisions about the design of any study will involve the determination of appropriate experimental and comparison conditions. In most instances the results obtained during actual tasks or missions should be compared to reference values collected under comparable conditions. There are four ways to do this: 1) comparing the results obtained during missions with values obtained during resting conditions, 2) comparing the results obtained during the actual mission with results obtained in the simulator, preferably with the same task, 3) comparing two or more actual missions or tasks that differ in difficulty, or in some other dimension, 4) comparing the results obtained during a mission with a preestablished, personalized response profile.

Relation to Other Methods

In general, psychophysiological methods should not be used alone. The most valuable information is obtained when these methods are combined with other techniques such as:

1) Questionnaires, such as scales on mental load or scales on effort, sleep quality, or fatigue.
2) Performance criteria and error analysis.
3) Observation and analysis of behavior.

Model Examples

The following examples will serve to provide illustrations of how psychophysiological measures are collected as part of studies in the laboratory, simulator, and under actual flight conditions. The three examples are brief summaries of studies which have recently been performed using both physiological and performance measures to address specific research problems. In each case, the utility of psychophysiological measures as well as the value of a multidimensional assessment strategy should be evident.

Laboratory study. This is an example of a project whose goal was to use psychophysiological and performance measures to assess the impact of doctrinal doses of atropine sulfate on the performance of Army helicopter pilots (Caldwell et al, 1991). The study included the collection of EEG and P300 data, cognitive data, and tracking data, as well as performance data from pilots flying a specially-instrumented Army helicopter. The goal was to fully examine the global effects of atropine on aviator performance.

Atropine sulfate is an acetylcholine blocker which has been fielded in 2 mg autoinjectors for use as an antidote to nerve agent poisoning. Since chemical nerve agents consist primarily of acetylcholinesterase inhibitors which produce an excess of acetylcholine at receptor sites, drugs like atropine are a logical treatment choice.

Mild exposure to anticholinesterase poisons produces symptoms such as anorexia, headache, weakness, and reduced visual acuity; whereas, moderate to high levels of exposure might be expected to produce symptoms ranging from bradycardia, nausea, and increased salivation, to respiratory difficulty, heart block, convulsions, and death. Immediate and adequate administration of atropine is the first priority after organophosphate poisoning has occurred. U.S. Army personnel are thus trained to recognize the symptoms of nerve agent poisoning and administer appropriate atropine therapy (up to 6 mg) in a timely fashion.

Although there is no question that atropine is an effective antidote to organophosphate poisoning, there have been concerns over the manner in which atropine may affect performance when it is injected because a soldier mistakenly assumes he or she has been poisoned. On the battlefield where there is a great deal of noise, smoke, and anxiety, it is conceivable that personnel could inaccurately perceive the presence of a chemical threat and initiate atropine therapy. Particularly in an aviation context where the slightest performance impairment may produce dire consequences, the consequences of such action should be explored.

In this study, 12 aviators were given a complete physical exam and a cardiac stress test prior to admission. They were outfitted with 25 silver cup EEG electrodes on the first day of the 11-day investigation, and they wore these electrodes for the remainder of the study--during both training and testing. In the test procedures, subjects were administered atropine and required to complete helicopter flight performance evaluations and laboratory tests on each of the dosage administration days. Subjects were administered one injection of either placebo, 2 mg, or 4 mg atropine on each of 3 different days which were separated by control days. Each subject was exposed to all 3 dose conditions, and during each condition, he was assessed with flight performance, vision, cognitive, psychomotor, and EEG tests.

The vision testing included an array of standard diagnostic tests for acuity, heterophoria, accommodation, stereopsis, and pupil diameter. Cognitive testing consisted of visual search, short-term memory, logical reasoning, simple mathematics, and reaction time tests. The psychomotor tracking test presented a laterally moving cursor on a dot matrix display, and the subject used a joystick to center the cursor over a target. EEG assessments included resting EEGs, visual evoked responses, and a visual P300 task. All of these data were collected in order to determine the effects of atropine on the aviator's ability to register and process information and to maintain basic cognitive and psychomotor skills. Also, the EEG tests were necessary to determine the effects of atropine on general levels of arousal and activation.

The flight performance testing included a series of upper-airwork maneuvers such as straight-and-levels, climbing and descending turns, standard-rate turns, etc.; confined-area recon, approach, and landing; low-level and terrain navigation; and flight under simulated instrument conditions. These data were collected to establish the effects of atropine on an aviator's ability to actually fly the aircraft.

On dose administration days, aviators first completed a predose baseline test session on vision, cognitive performance, psychomotor tracking, and EEG measures. Then the aviators were escorted to a specially instrumented UH-1 helicopter equipped with flight and physiological monitoring equipment. Once the instrumentation was verified and the aircraft was prepared to depart, the injection of either placebo, 2 mg, or 4 mg atropine was given. Then the subjects, with a safety pilot, completed a 2-hour flight consisting of the components mentioned above. Physiological data were not collected during the flights.

At the conclusion of each flight, subjects returned to the laboratory for another session of vision, cognitive, tracking, and electrophysiological tests. Afterward, there was an afternoon flight identical to the one earlier in the day, and following this flight, there was an additional laboratory test session.

Results indicated numerous atropine-related difficulties, seen most often with the 4 mg dose. Measurements of flight performance revealed decrements on at least one measure (i.e., heading, air speed, vertical speed) in both visual- and instrument-referenced straight and level flight, standard rate turns, a straight climb and descent, steep turns, a climbing turn, and an instrument landing system (ILS) approach. Also, there were degradations in performance of a confined area approach and an out-of-ground-effect hover maneuver. Some subjects evidenced other significant in-flight problems and there were often transient personality changes under 4 mg. Vision tests showed atropine-related increases in pupil diameter and double vision, concurrent with decreases in accommodation and near depth perception involving fine detail. Cognitive tests revealed decrements in visual search, logical reasoning, quantitative ability, short-term memory, and choice reaction times. Psychomotor tracking tasks indicated atropine-induced increases in tracking errors across three levels of tracking complexity, and these were sometimes accompanied by deficits in responding to a secondary task. Electrophysiological data revealed a number of effects on resting EEGs, such as increased delta activity, a reduction in alpha activity, and longer P300 latencies, which were consistent with the observed atropine-related performance problems. Through examination of the performance tests combined with the EEG data, it was noted that the effects of 4 mg of atropine would become manifest within 30-50 minutes postdose and persist for over 8 hours (although vision impairments often lasted even longer).

These results were interpreted to indicate that atropine exerted numerous effects on basic brain and sensory functioning which ultimately led to substantial performance decrements. For instance the reduction of alpha activity and the increase in delta activity were both indicative of sedation which is consistent with the reduced rate of responding and lower accuracy on cognitive tests. Also, there were changes in visual evoked responses which were thought to evidence atropine's effects on vision which had also been revealed by basic vision tests. These problems (reduced alertness and impaired vision) no doubt combined to produce the tracking errors and flight performance decrements observed in this investigation.

Overall, the study found that performance at higher altitudes under the influence of up to 4 mg of atropine did not appear to be critically impaired, but performance close to the ground which required tight control of the aircraft did reveal problems. It was concluded that the severity of these atropine-related decrements probably would increase under the "real world" scenarios of training or combat. The EEG data greatly contributed to the performance data by offering a physiological explanation of many of the performance problems in addition to revealing drug-induced changes in aviator functioning which were not obvious based on basic skills tests.

Simulation study. In this project, the goal was to use psychophysiological measures to monitor situational awareness in a simulated air-to-ground scenario (Stratton, Wilson and Crabtree, 1993; Vidulich, Stratton, Crabtree and Wilson, in press). Pilots' situational awareness or their global view of the entire situation in which they are involved is being seen as an important part of mission success. This is especially true in single seat fighter aircraft. Since a pilot's situational awareness requires the collection of environmental information and, most importantly, the processing and synthesis of this information it was felt that EEG measures were required. Since the greatest portion of the sensory input was visual, eye blinks were used to monitor visual demand. Heart rate was collected because of its ability to detect overall changes in subject state. The simulator was setup as an F-16 fighter aircraft with either one front view screen which included a heads-up display (HUD), representing a day time mission, or two screens, one with the HUD with a night time background and the other representing a global positioning satellite (GPS) image. The subjects were to locate and destroy ground targets which were enemy tanks. In the two-screen night scenario, the targets appeared as white dots on the HUD display. The two screen version was predicted to interfere with the subjects' situation awareness since the needed information about the location of the tank targets had to be acquired from two displays which would make it more difficult for the subjects to maintain the required information in memory. Each scenario lasted for approximately three minutes and consisted of a simulated flight through mountainous terrain. The objective was to locate and destroy the enemy tanks. Surface-to-air (SAM) warnings occurred on one half of the trials. Fourteen unique scenarios were used in the simulation.

The twelve subjects practiced for approximately 28 hours each in order to gain proficiency with flying the simulator and locating and shooting the targets. When the subjects were proficient in the task, they were asked to return to the laboratory for the physiological data collection while they performed the simulation. Since the main area of investigation was the subjects' situational awareness, twenty channels of EEG data, heart rate and eye blinks were collected.

When the subjects arrived at the laboratory they were fitted with an elastic electrode cap which held the 20 electrodes and which could be rapidly positioned with sites distributed according to the International 10-20 system. Electrolyte gel was injected through holes in the center of the electrodes and impedance was reduced to 5,000 ohms or less. A commercially available EEG topographic system was used to collect and reduce the data. Disposable Ag/AgCl infant size ECG electrodes were used for recording eye blinks and heart rate. In order to record eye blinks, the electrodes were placed above and below one eye. Snap lead connectors were used for electrode leads. The ECG leads were positioned just below the notch of the sternum and on the left side of the chest over the fifth intercostal space. An electrode on the right side of the chest served as ground. Data collection began with a signal from the simulator computer so that flight events could be correlated with the physiological data.

The EEG data from each of the twenty channels was reduced by the Fast Fourier Transformation (FFT) and the energy in the delta, theta, alpha and beta bands was estimated. Data segments contaminated with eye blinks and other artifacts were not used in the analysis. Mean heart rate, blink rate and blink duration were also calculated. The analyses were performed on each of the scenarios, including a preflight baseline condition, and also on the portion prior to and following the SAM warning or when the SAM warning would have occurred.

The results showed that the theta band power increased in the GPS conditions in the frontal, central and right parietal brain regions. This was true for more of the SAM-off conditions than for the SAM-on conditions. There also was a significant decrease in alpha band power in the frontal sites during the GPS SAM-on condition. Blink durations decreased significantly in the GPS compared to the day time condition. Heart rate was not significantly affected by any of the experimental conditions. A subjective measure of situational awareness confirmed that the subjects felt that their awareness of the overall situation was reduced during the GPS conditions.

The results were interpreted to indicate that the GPS situation was the most difficult and the one most prone to loss of situation awareness. The higher levels of theta activity were indicative of increased cognitive involvement which meant that these conditions could be more prone to error and loss of the status of the various portions of the mission. This interpretation is consistent with a task analysis since the GPS condition required that the needed information be acquired from two separate displays and integrated by the subject. For the day time condition, all of the needed information was available from one display. The blink duration data also supports this notion since blink duration decreases have been found in a number of other situations which are high in visual input demands. The lack of heart rate effects is probably due to the more global nature of this measure which seems to lack the sensitivity to separate the differences between these conditions.

Field study. The following is an example of a flight study that was designed to measure the mental workload of F4 fighter/bomber pilots and weapon systems officers (WSOs) during air-to-ground training missions (Wilson, 1993; Wilson, Fullenkamp and Davis, in press). The F4 provides a unique opportunity to monitor the mental workload of two people simultaneously who are at the same place at the same time but who have different jobs and responsibilities. Further, the experiment was designed to assess the similarities in physiological data between flying and performance of a laboratory tracking task that has been used to manipulate mental workload in what has been called a task related to flying. Another goal was to determine the utility of several physiological measures to assess the mental workload of the several segments of the entire air-to-ground missions. Heart rate, heart rate variability, eye blinks, respiration and brain evoked potentials were used.

In order to have sufficient statistical power, ten F4 crews each flew one mission. The research protocol was approved by the local Human Use Committee. The squadron was briefed by the experimenters who outlined the goals of the project and described the data collection procedures. Crews were then asked to volunteer to be subjects in the study. Their participation included several hours practice on the tracking task to ensure that performance was stable so that any subsequent changes would not be attributable to practice effects.

On the day of data collection for each crew, they arrived at the life support room approximately one and one half hours prior to mission briefing. The pilot and WSO were instrumented with the required electrodes--disposable Ag/AgCl electrodes were used for the ECG, a strain gauge band was fixed to the chest for respiration, and reusable Ag/AgCl electrodes were used for the EOG and EEG. Electrodes and the leads were positioned so that they did not interfere with movement and other equipment. The subjects wore cloth helmet liners and did not report discomfort with the EEG or any other of the electrodes and equipment. Shielded electrode leads were used to reduce artifacts produced by movement of the leads over the body surface. Artifacts which were observed were primarily "biological" in nature as opposed to being produced by nearby electrical equipment, radios, etc. In other words, the artifacts were typically attributable to movement, muscle end eye activity that interfered with the other physiological signals. Small ambulatory, neurological, tape recorders were used to collect the data--they were connected to the electrodes via an electrode block and cable. The recorders weighed about one pound and easily fit in one of the leg pockets of the G-suit. The recorders had a timing track that could be set to the second. The time was synchronized with the mission clock and a voice/time code recorder that recorded the cockpit communication and also had a time marker accurate to one second. This permitted the correlation of the physiological data with mission events.

The participants gave subjective workload estimates following the mission. During two cruise segments, the pilot listened to tones that were presented via a small speaker worn inside one cup of their head set. A pulse that corresponded with the onset of the tones was recorded on one channel of the physiological recorder. This pulse was used to derive brain evoked potentials. Since evoked potentials had not previously been recorded during flight the main goal was to determine if they could be recorded. The secondary goal was to see if they had utility for monitoring mental workload. This was accomplished by using one segment when the pilot was flying the airplane and a second flight segment when the WSO was flying the aircraft. By using cruise segments it was felt that flight safety would not be jeopardized and the collection of valid data would be permitted.

In order to make data analysis and interpretation manageable the mission was divided into 14 two-minute segments. The segments included a resting baseline, the tracking tasks at two levels of difficulty, the pre-flight briefing, take-off, cruise to the bombing range, the bombing range, cruise back to base and landing. Mean data from each of the physiological channels were used in the statistical analysis. Analysis of variance was used to test for segment and crew member effects. Paired comparisons tests were used to establish which segments were significantly different. These analyses permitted the establishment of which segments were associated with different levels of workload and if there were differences between the pilots and WSOs. Since the physiological data differed between subjects in the baseline segments, each subjects' data were expressed as percentage change scores relative to their baseline segment. The data demonstrated that the pilots responded with greater changes in their physiological data in all of the flight segments except the WSO flying segment.

Overall the heart data showed graded changes that corresponded to the subjective workload ratings. Increased workload was associated with increased heart rate. The heart rate variability measures did not show as much sensitivity as the simple heart rate measure. Eye blinks were good measures of visual demand with the bombing range producing lower blink rates and shorter eye closure durations than the other segments. The pilots' blink rates at landing were also low. Respiration, for the most part, mirrored the heart data. The brain evoked potentials from the two cruise segments, pilot flying and WSO flying, showed that the P200 component amplitudes were smaller when the pilot was actually flying the aircraft. These data demonstrate that evoked potentials can be collected during flight and that they can provide meaningful data.

The tracking task changes were smaller than any of the flying segments. The comparison of tracking task to flight data showed that the laboratory type task did not produce changes in the physiological data that were at all comparable. The changes during the tracking task were of the order of five to ten percent while the flight changes were from 20% to 50%. There were significant differences among the data from the flight segments for both the pilots and WSOs. To pursue this further and to see if the physiological data could be used to classify the segment of flight, linear stepwise discriminant analysis was used to classify the flight segments (Wilson and Fisher, 1991). The pilots and WSOs were all correctly classified, 95% of the pilot segments were correctly classified, and 98% of the WSO segments were correctly classified. Validation of these results require two flights for each crew so that one flight can be used to develop the classifier and the other to test the classifier. However, the statistical jackknife procedure was used on the available data to estimate the reliability of the classification accuracy and showed that this approach should be quite accurate.

This experiment and the associated analyses were fairly complex because it was felt that the most should be achieved with the flight data since the opportunity to collect in-flight data is rare. This provided the opportunity to answer several related experimental and applied questions.

Summary

The collection and analysis of psychophysiological data in both field and laboratory settings presents a variety of challenges. However, as can be seen from the examples presented above, the addition of physiological measures can be of substantial benefit in terms of explaining behavioral changes and directly evaluating the functional status of operators. Although psychophysiological data will not replace behavioral observations or performance tests, they can be used in conjunction with these more traditional measures to obtain valuable information.

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Appendix A
ACTIVITY

General background

Actigraphy is a convenient technique for the study of vigilance, sleep, and circadian rhythms. Various methods have been developed to quantify motor activity. Three will be reviewed here. Only the first one has been applied to in-flight experiments. However, applications can be found in the operational context.

On the one hand, the selection of the appropriate techniques depends on the type of experimental context. In the case of an operational situation, with the freedom of movement available to the subjects, the choice of actigraphy by detection of wrist motion is obvious. In the case of a restricted movement area or of a laboratory experiment, it's possible to choose actigraphy using video display sensors or actigraphy by the processing of video frames on a micro-computer. On the other hand, the choice of techniques depends on the measured parameters. The first technique (presented below) measures only locomotor activity, the second and the third permit the evaluation of activity and the behavior of subjects by video analysis. In each case, the three methods can be associated with other techniques such as EEG, temperature, EMG, and heart rate without interfering with the actigraph measure and could also be very helpful with data interpretation.

Actigraphy by the detection of wrist motions

Material. Commercial equipment usually consists of a wristwatch like unit, a micro-computer with actigraph initialization and treatment programs and an interface unit (see figure 4). The watch-strap can be adapted to be worn on the leg or on the belt. The wrist-watch contains a three axis accelerometer sensor with preamplifier and filter which can be interfaced to a microprocessor by a multiplexed analog-digital converter. The microprocessor uses storage memory to record the collected data. The power supply of this device is generally a lithium battery.

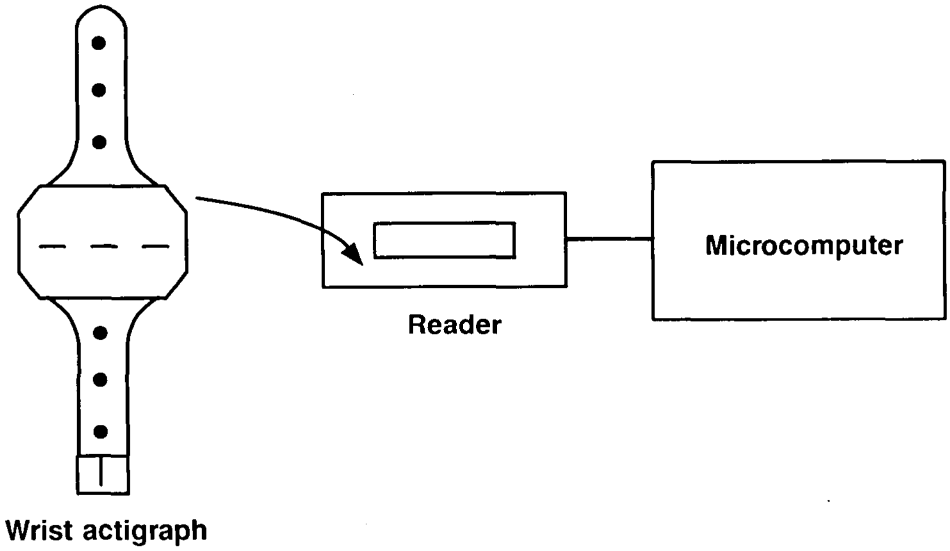

Figure 4. The Ambulatory Monitoring actigraph stores certain events such as the number of times the motion signal passes over zero. A signal reader removes data from the wrist recorder's memory and transfers it into a microcomputer for processing.

The wrist-watch unit is programmed by the microcomputer and retrieval of the data is also accomplished with this interface. The microcomputer contains standard analysis software which permits sleep state scoring, basic statistics and several forms of visual presentation.

Procedure. First, the wrist-watch unit is programmed for the epoch interval, the start delay, the event marker and sensitivity parameters, filter cutoff frequencies, level of the detection threshold and the gain. The wrist-watch unit is worn by the subject for the entire experiment. When interesting events occur, the subject can press an event marker button. Movements of the wrist are recorded if their energy is sufficient to exceed the programmed threshold.

Recording equipment. The recording equipment is contained in the wrist-watch unit. Commercial versions contain 28 K bytes for data storage which is enough for two days of continuous recording and storage with an integration period of 1 min.

Signal analysis and processing. The analysis is accomplished by visual presentation of the activity during an epoch of a few minutes, hours, or several days. The data are presented in a graph where the vertical axis represents activity counts per epoch and the horizontal axis represents time. The activity (vertical axis) is expressed in time over threshold or the number of zero crossings during a defined time period. Different levels of activity are represented by discrete vertical lines of different amplitudes. Typically, these graphs are scored by both computer algorithms and a human observer (who checks the computer scoring). Once the validity and proper scoring of the data have been established, standard statistical tests can be performed.

Actigraphy by the detection of wrist motion, in-house systems

Material. Laboratory developed systems have been built using strain gauges. A thin strip of steel (0.1 mm) is fixed to the back of the hand and on the forearm in the direction of metacarpal and radius bones. Two strain gauges are attached over the steel strips and the gauges are protected by covering them with a plastic covering. They are connected to an electronic conditioning circuit. The output signal of this device can be recorded on a digital or an analog ambulatory recorder. It also can be sent to the recorder or analysis device using portable telemetry equipment. The signal is then digitized and analyzed by a micro-computer.

Procedure. The sensor can be fixed on the skin with double faced adhesive tape, so that the gauge orientation will be on the correct axis. The ends of the sensors should be free to move on the skin and petroleum jelly can be helpful. A latex glove can be used to cover the hand to keep the sensor on the skin. To quantify the movement in degrees of movement angle, the equipment must be calibrated on the subject to establish a mathematical relation between the angle of movement and the output voltage.

Recording equipment. The output signal of the electronic circuit can be recorded or transmitted. In the case of a recording, an ambulatory magnetic instrumentation recorder must be used, which permits the recording of other parameters. Either analog or digital recorders can be used. In the case of transmitted signals, telemetry has been used by Ranaivosoa, Cnockaert and Lepoutre (1990). The signal can then be directly recorded and analyzed by a micro-computer.

Signal analysis and processing. The analysis is accomplished as described for the specific type of commercial equipment being used. The data may be presented in graph form where activity is represented in degrees of movement per unit of time.

Actigraphy by the use of video display sensors

Material. The subject(s) is (are) filmed using one or more video cameras. If they must be filmed during night periods, CCD video cameras can be used with ambient infra-red lighting. Commercial devices are available which can divide an image into 4096 sensitive areas. The location of these areas is determined using an optical scanner. The sensitivity of detection can also be adjusted as well as the number of sensors that are used in order to record motion. Theoretically, the system is not sensitive to changes in lighting as it operates by comparing successive pictures. The generated binary signals can be easily picked up by a micro-computer. Video monitors permit the operator to visualize the subject(s) and the video sensors (see figure 5). The micro-computer must be equipped with a commercial timer card programmed in "event counter" mode.

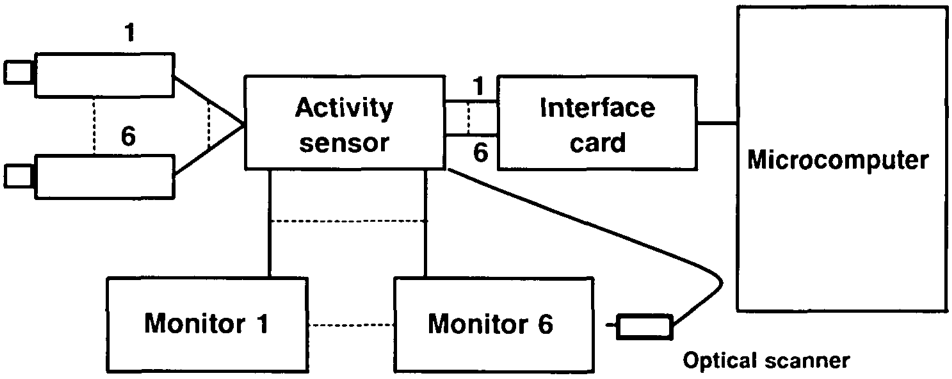

Figure 5. A commercial system which can process up to 6 video inputs simultaneously. Sensors embedded in the video pictures are located by optical scanning.

Procedure. Adjustments must be made to the experiment to establish the sensitivity levels of the video sensors to match the lighting levels for day or night recording. Also, if important and frequent changes of ambient light levels occur, the sensitivity must be appropriately chosen. Usually a lightpen is used to place the sensors on the screen. If the subject(s) have to make large movements or change positions, the selection must be made with great care.

Recording equipment. The motion detector generates binary signals. The binary signals and the time values from the timer card are recorded on the hard disk of the micro-computer. If the analysis is done off-line, the video signals must be recorded on a high quality video recorder in order to provide high contrast and a good signal-to-noise ratio.

Signal analysis and processing. The analysis is the same as that described for the wrist motion commercial systems. The activity is expressed in number of seconds containing motion.

Actigraphy by processing frames on a micro-computer

Material. As with the previous method, the subject is filmed by one or several cameras. If filming is done during night periods, CCD video cameras should be used with ambient infra-red lighting. Signal outputs from the cameras are digitized by a card in the micro-computer (see figure 6). This card is capable of making real time calculations for comparison of successive frames. Many companies sell processing cards for micro-computers which have the needed speed and power to execute complex mathematical operations in real time on a great number of points.

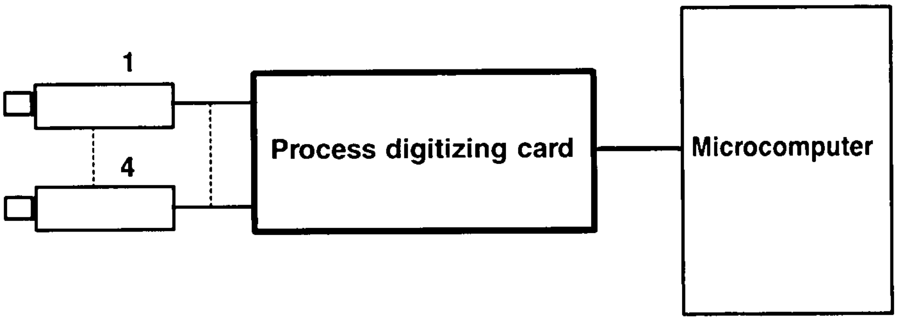

Figure 6. A digitizing card is inserted into the microcomputer where it digitizes pictures so that certain calculations can be made such as contour extraction and picture convolution.

Procedure. The analysis software has usually been developed specifically for each experiment. So, the procedures have to be adapted to each laboratory or experiment.

Recording equipment. The processing of pictures can be made in real time or off-line from recorded signals. High quality video recorders must be used to provide a good signal-to-noise ratio.

Signal analysis and processing. Due to the power of this method, signal analysis and processing will be tailored to each application.

Example of operationally-oriented studies using actimetric recordings

This example is from a study completed during an exercise by French Air Force air crew in 1988 (LeMenn, Serra, Muller, and Bouron, 1988). A number of parameters including actimetry were evaluated during an exercise of operational readiness in a confined environment over a period of 10 days, in order to assess the response capability of the aircrew at the end of this period of time and to test the efficiency of the shelters. The aircrew was constantly monitored on a TV screen. A CCD camera, its conditioner and a multi-directional microphone were placed in the three rooms considered to be the most important for group living. A special system for partial counting of the activity in the viewed rooms was correlated with the video film data, also used for the behavioral study, in order to study the mean locomotor activity of subjects appearing on the screen in periods of 10 minutes. Results showed higher activity in the "living room" than in the "operation room". Activities were intense during the daytime and practically non-existent at night. There also was greater activity during the first and last three days of the exercise compared to the four middle days. The change in actimetry was perfectly correlated with two criteria related to sleep quality identified by responses to questionnaires. This phenomena can be explained by the exposure to a new environment requiring time for adaptation (first phase), by the installation of a certain routine in living habits including sleep (second phase), and the anticipation of the release from this environment, with a disengagement from ties that had been established and uneasiness about returning into "normal" life, associated for certain subjects with an evaluation of performance (third phase). This can be seen in figure 7.

Thus, the technique of actigraphy by image processing provides a reliable picture of the daily activity of subjects with its changing aspects which can be interpreted with respect to other psychophysiological parameters.

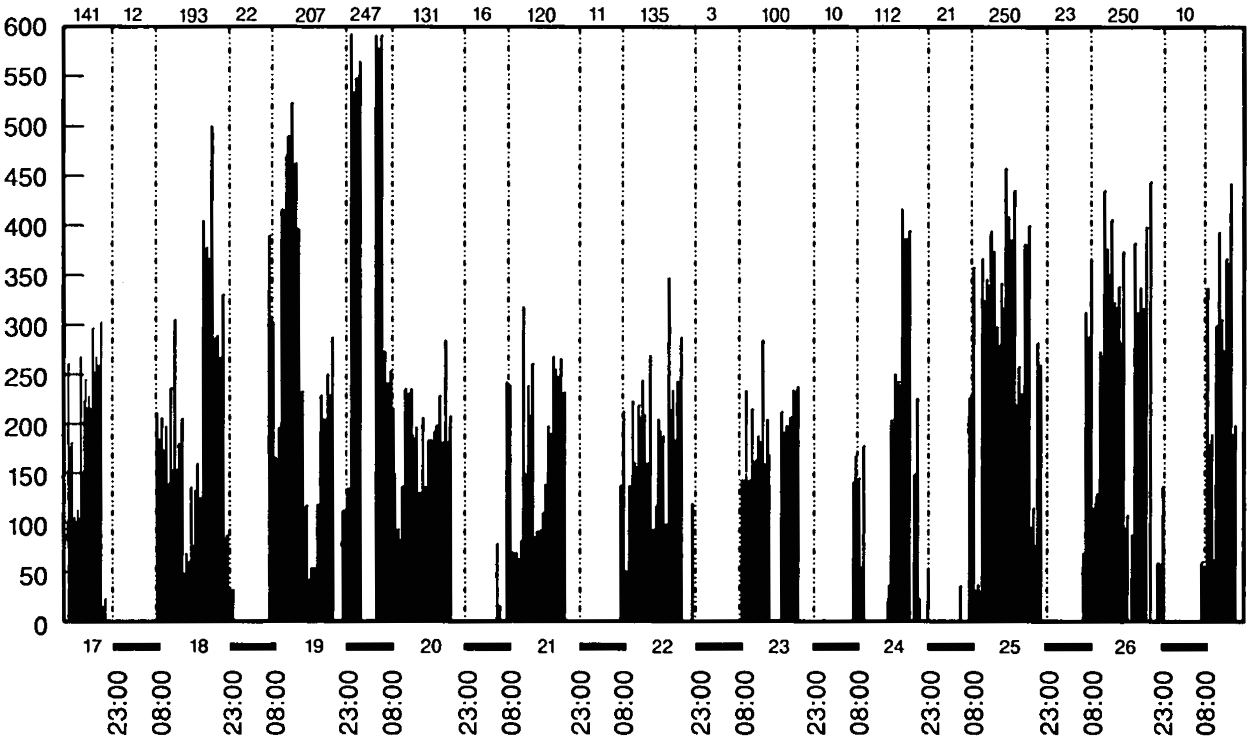

Figure 7. An example of actigraphic data derived from video monitoring from a study by the French Air Force. The three phases of subjects' activity are depicted in this graph. On the 17th, 18th, and 19th day: high activity; on the 21st, 22nd, and 23rd day: low activity; on the 25th, 26th, and 27th day: moderate increase in activity (see text).

Appendix B
BRAIN

Spontaneous EEG

General background

Measures of brain activity are often chosen to study the impact of various stressors on human functioning. Investigations of mental workload, cognitive processing, vigilance, alertness, and performance often include electroencephalographic (EEG) recordings because an examination of the EEG provides an assessment of the brain activity underlying mental and psychological functioning. EEG patterns change as a function of alertness or arousal and these changes can be useful in understanding changes in performance.

The EEG may be recorded in applied settings and in laboratory-based studies to establish information that is directly applicable to the operational environment. To be useful operationally, a physiological variable such as EEG must clearly be related to a behavioral outcome. Whenever possible, measures of performance and subjective ratings should be recorded to complement the physiological recordings. Additionally, for ease of interpretation and avoidance of artifact contamination, EEG recordings should be accompanied by concurrent measures of eye movements and muscle activity. This is especially true when the investigator is using only a small number of EEG leads as opposed to a full 10-20 montage (where muscle and eye-movement artifact can be identified from an examination of certain EEG channels).

EEG activity is usually described in terms of the clinical frequency bands of delta, theta, alpha and beta. Alpha and theta activity are of the most interest as arousal changes. Alpha activity is generally suppressed by mental activity, and recordings with eyes closed generally contain more alpha, with a frequency generally lower than in the eyes open condition. There is great individual variability in alpha activity, in terms of abundance, amplitude, and dominant peak frequency. Some subjects have no discernible alpha rhythm, although activity exits in the frequency band as a continuum, and recordings consist of either slow activity while the subject performs tasks normally, or fast (beta) activity that can be either highly variable in frequency content or have a similar morphology to alpha activity but a higher frequency. Alpha reactivity as a subject closes his eyes or responds to tasks differs between individuals, with some subjects having a highly persistent rhythm.

However, in the typical case, alpha decreases with increases in alertness, but as incipient drowsiness approaches, the alpha rhythm breaks up, beginning to fluctuate with short periods of theta activity appearing. The subject may then return to a more alert state with alpha present, or progress towards drowsy sleep, characterized in the EEG by theta activity. Incidences of drowsy sleep are common during monotonous tasks both in the laboratory and in occupational settings.

Equipment requirements

Electrodes. EEG signals can be recorded from a variety of scalp locations with small electrodes (about 8 mm in diameter) constructed of silver, silver-silver chloride, gold, or tin. Silver-silver chloride electrodes are often preferred because they do not polarize (develop an electrical charge of their own) as rapidly as electrodes constructed of other material. Polarization can be a problem when recording certain types of physiological data because an offset or bias potential develops due to the recording apparatus (the electrode) rather than the physiological system of interest. Also, polarized electrodes can create apparent resistance problems which cannot be resolved by further cleaning of the subject's skin. All of the electrodes employed in a montage, including ground and reference electrodes, should be made of the same material (Stern, Ray and Davis, 1980; Andreassi, 1989).

Amplification and recording equipment. A number of different types of amplification and recording systems are available, and the choice depends on application requirements (Stern, Ray and Davis, 1980). Clinical EEG assessments are usually made with multichannel systems designed exclusively for EEG recordings whereas laboratories often use more limited, multipurpose systems. The equipment may consist of the traditional ink-writing polygraphs or the newer computerized acquisition and analysis systems. Generally, the equipment is designed to test a patient or subject who remains stationary in a chair or a bed in a quiet room; however, there are ambulatory monitoring systems which can record or telemeter EEG data from someone who is moving about freely.

Regardless of the particular application, the recording equipment must be able to amplify very small signals from 5 microvolts to over 100 microvolts and require gains of 20,000 and higher. Distortion free amplification of up to 1 million times the original signal is desirable. The amplifiers should be capable of accurately following frequencies from 0.5 Hz to 100 Hz. Also, there should be a provision for filtering out unwanted electrical interference (such as the 60 Hz or 50 Hz signals produced by various electrical equipment). In addition, it is useful to have signal-conditioning filters which allow the isolation of particular EEG frequencies by "filtering out" activity which occurs above and below the frequencies of interest (See Cooper, Osselton and Shaw, 1980 for a review of EEG recording procedures).

EEG activity is normally recorded from occipital, parietal, central, and frontal sites from the midline and from over both hemispheres. The active sites on the scalp are referenced to relatively inactive sites such as the mastoid processes behind the left and/or right ears. For standard EEGs, linked or averaged mastoid references are commonly used, but there has been considerable discussion about choosing reference sites (Nunez 1981). In particular, the pattern of evoked responses depends markedly on this choice, and thus when recording evoked response data, some investigators recommend against the use of a single reference electrode. Instead, it is recommended that several references be used and that the data are converted to source derivations or average reference derivations after the data have been stored in a computer. The converted signals are independent from the reference signal.

Regardless of the reference chosen, when recording EEGs, there should be enough separate channels (amplifiers) to monitor a minimum of 4-6 electrodes, but systems are available that can collect over 20 channels. If the number of channels is limited, changes in alertness are most easily seen in the occipital and parietal derivations.

Recording the amplified data for subsequent analysis is accomplished in two ways, using either a standard ink-writing polygraph or a computerized system. With a standard polygraph, the data of interest from each EEG channel are recorded on paper. Once a recording session is complete, a technician visually scores each record to determine how much of particular types of EEG activity occurred during specific time intervals. With a computerized EEG collection and analysis system, the data are displayed on a CRT and stored on magnetic disk or tape for later analysis. In computerized systems, the EEG is digitized at a rate which exceeds the highest frequency of interest by a factor of at least 2 (the Nyquist frequency). Thus, a sampling rate of 200-250 Hz is suggested for good accuracy at the higher end of the EEG frequency range. The stored data can be analyzed by the computer, i.e., determining the energy in the several frequency bands.

Amplifier settings. The low frequency filter (high pass) should be set between 0.1 and 0.5 Hz (generally the lowest one available), and the high frequency filter (low pass) to between 70 and 100 Hz (for some applications, a setting of 30 Hz may be used). It may be necessary to engage a 50 or 60 Hz notch filter if external electrical interference is a problem. Generally speaking, it is good practice to collect data with the widest filter settings possible since this reduces the chances that valid EEG data will be obscured by filtering. Also, it is better to avoid the use of a line frequency (50-60 Hz) notch filter unless there is a compelling problem with electrical interference.

Recording Procedures

Electrode placement. Normally, electrodes should be placed according to the International 10-20 guide, which describes the standardized location of 19 active EEG recording sites (Jasper, 1958). After the scalp is measured and the placement sites are marked, the hair should be parted (not cut), and each site should be cleaned with a specialized preparation, alcohol, acetone or soapy water in order to ensure impedances between electrodes of 5,000 Ohms or less. Low impedances increase the quality of data recording by improving common-mode rejection of extraneous electrical interference. After cleaning, the electrodes may be attached with electrolyte paste and tape or with collodion. If a multichannel EEG is to be collected, the investigator may want to use an electrode cap instead of placing 15-20 electrodes individually. These caps are usually made from elastic fabric, and tin or Ag/AgCl electrodes are integrated in the cap. Caps are commercially available from different manufacturers. The number of electrodes and electrode positions can be chosen according to the International 10-20 System but caps also can be custom-made. After applying the caps, electrodes are filled with conducting gel or creme. Caps can be applied very easily and may considerably reduce time that is needed for a hook-up; however, the electrode placements are not as accurate as the ones which can be obtained by placing individual electrodes one at a time.

Subject preparation. Subjects, in laboratory settings, should be told that slight muscle movements, talking, chewing gum, clenched teeth, excessive eye blinks, etc. will all seriously interfere with the collection of "clean" EEG signals. They should be asked to minimize any of these types of movements or activity whenever possible. A brief pretest recording period helps assess whether subjects are having difficulty relaxing in the test situation so that problems with excessive blinks or movements can be corrected early on. In situations where certain types of movement artifacts cannot be eliminated, the researcher may consider using computerized or other artifact-correction routines.

EEG recording. All of the EEG channels usually should be set to the same filter parameters and sensitivity so, for example, a 50 microvolt signal will appear the same size on all channels. This will ensure that comparisons can be made from one channel to another within the same record. Also, if the same settings are maintained from one subject to the next, comparisons across subjects will be easier. Recordings typically should include a standard calibration signal (for example, a 100 Uv, 10 Hz signal) at the beginning and end of each experimental session. After calibration, a baseline recording should be made to establish each individual's normal EEG pattern. Ideally this is carried out with the subject seated in a quiet setting, and includes recording with eyes open for at least 30 sec while the subject fixates on a point, followed by at least 2 min with eyes closed with the subject resting. Checks of signal quality should be performed at this time, including EOG (e.g., 5 blinks, 5 saccades) and EMG (e.g., gritting teeth, moving the neck) channels, if used, to ensure that each recording channel responds as expected. Once the signal quality has been verified, the actual recording period may begin.

Artifact rejection/correction. During recording periods, it is necessary to monitor the data to ensure that any controllable artifacts from subject movements or blinks can be eliminated. Prior to data analysis, the EEG signals should be examined for the presence of any remaining artifacts which were beyond experimental control. Depending on the situation, one can reduce the influence of artifacts by: 1) using an analysis procedure where only artifact-free epochs are analyzed, or 2) using an artifact correction procedure. Rejecting data containing artifacts from analysis can be problematic in situations where short data segments are used or where mental events are short lived and removing artifact segments could remove the data of interest. Artifact correction procedures may be able to retain the needed data segments. A number of artifact correction procedures have been developed, mostly for eye contamination. The reader should survey the EEG literature for current methods. Since EEG data contains frequencies which overlap the typical frequencies of eye movements (or blinks) and muscle activity, it is helpful to record EOG and EMG data along with the EEG to identify epochs where artifacts are present. Without these additional channels, it may be impossible to determine whether the EEG is contaminated, particularly when collecting only 2-4 channels of data.

Data Analysis

Basic procedures. EEG data can be analyzed either through visual inspection of a paper record or through computer algorithms available on computerized data collection and analysis systems. Some types of EEG recordings are typically made on standard polygraph paper and are scored via visual inspection. For instance, sleep EEG records are scored one page at a time using specific rules about the amplitude, frequency, and duration of the EEG signals which provide information about sleep stages (Rechtschaffen and Kales, 1968). Other types of EEG records are also visually scored such as the records obtained from patients seen for clinical electroencephalographic examinations. In this case, the patient's EEG is examined for the presence and duration of certain types of abnormal activity such as spikes or seizure discharges although the amount of delta, theta, alpha, and beta activity can be determined as well.

The most frequently used method of analyzing EEGs collected on computers is spectral analysis, with spectra being represented by the clinically defined frequency bands, typically delta (1-3 Hz), theta (3.5-7 Hz), alpha (7.5-12 Hz), and beta (above 13 Hz), although the frequency ranges vary among laboratories. Peak alpha frequency and variability of the above measures are also usefully included. In addition, it is possible to analyze each separate frequency across the entire spectrum if more resolution is desired. Alternatively, spectra may be defined by analytical methods such as principal components analysis. With spectral analysis, the signal is subdivided into short epochs usually with a duration of 1, 2, or 4 seconds to provide approximate stationarity, a data window is applied to compensate for epochs of finite duration, and then the Fourier transformation and calculation of power spectra is performed. Power spectra can then be displayed as a function of time using a compressed spectral array or frequency bands plotted as a time series. Maintaining time resolution on the order of several seconds is important from the point of view of detecting changes in alertness relevant to performance, as well as correct methodology. There is obviously a tradeoff between stationarity and frequency resolution. It is important to ensure that data which is to be analyzed with FFT procedures is sampled, filtered, and digitized properly to prevent aliasing. It is necessary to sample at a rate which is twice the highest frequency <u>of interest</u> with higher frequencies which may be present filtered out with a low-pass filter prior to digitizing, or to sample at a rate which is twice the highest frequency actually <u>present</u> in the data. Otherwise, the higher frequencies may be misinterpreted as lower frequencies. It may also be necessary to "window" the data in order to minimize stability and/or leakage problems. A complete description of Fast Fourier analysis has been prepared by Dumermuth and Molinari (1987).

Other methods commonly used are digital filtering, autoregressive modelling, zero-crossing analysis, Hjorth's measures of activity, mobility and complexity, coherence analysis and phase spectra. Techniques to allow for the non-stationary nature of the EEG have also been developed, e.g., adaptive segmentation. The reader can consult one of many reference texts for details (Gevins and Remond, 1987).

These procedures provide a primary analysis and before their application, suitable artifact correction or rejection techniques must be applied to ensure that the activity being analyzed is of cerebral origin, since artifacts can frequently be large in amplitude and have undue influence on the analysis of the study.

The chosen primary analysis procedure is then followed by a data reduction process (e.g., calculation of mean power spectra for experimental sessions or segments of a field study, classification of epochs into states according to alertness by discriminant analysis or cluster analysis to indicate for example the amount of sleepiness over a given shift). Statistical analyses of the reduced data set is then carried out according to the experimental design of the study. Some authors suggest transforming the spectral data prior to statistical analysis to better approximate a normal distribution, e.g., log transformation (Lopes da Silva, 1987).

Topographic Information. An EEG time series records the running net algebraic difference between all electrical activity generated in the brain or muscles and reaching the pair of recording electrodes, which are analogous to antennae picking up disparate radio sources. However, unlike radio, in which stations broadcast their signals in separate, clearly-defined frequency bands, meaningful electrical activity from brain (and muscle) sources is picked up in wide and often overlapping frequency bands (from 0.1 to 200 Hz). Compounding the problem of identifying sources of brain potentials is the fact that brain electrical energy arising from discrete sources (e.g., from small oriented patches of sensory cortex), is smeared out as it passes through the skull and scalp. Therefore, the actual scalp topography of EEG produced by just a single brain generator site is a function of the strength and orientation of the generator region, the resistance of the intervening media (most importantly the skull), and the placement of the recording electrodes (Nunez, 1981). Moreover, most EEG or evoked response features related to cognitive processing are the sum of activity generated at several disconnected sites (Naatanen and Picton,1987).

The inverse solution to the problem of determining the arrangement of electrical generators inside a closed body from the pattern of electrical potential on the surface has long been known to be non-unique, uniqueness being guaranteed only when the problem is highly constrained by specifying in advance the number, size, and/or arrangement of the generators (Nunez, 1981). Unfortunately, for EEG this additional information is usually not known in advance.

Despite these problems, however, in most cases more useful information can be extracted from multi-channel recordings than in single channel recordings. However, extracting this information from the massive amount of EEG data collected in multi-channel experiments is not straightforward. Approaches currently in use include topographic mapping and spatial or spatio-temporal Principal Components Analysis, which can be performed in either the time or frequency domains (McGillem and Aunon, 1987) although time domain analysis is more frequent.

Source localization software is now beginning to be commercially available--the best known package currently being Scherg's BESA program (Scherg and von Cramon, 1986), which can find a local minimum error solution given a suggested generator structure entered using a convenient graphic user interface. However, the solution found by the program represents only the location of a more or less local minimum in residual error of fitting the model to the actual data. Mathematical simulations have shown that for most data of interest, many nearly equally deep local minima can be found in the error surface for the inverse problem. Thus the program can arrive at very different but approximately equally good fits, given different starting points.

Further progress in electromagnetic source localization may come from software which uses some combination of magnetic resonance imaging (MRI), EEG, and simultaneous magnetoencephalographic (MEG) measurements, and finds models constrained to having sources in the actual cortical volume with orientations normal to the cortical surface. While current progress toward such software is rapid (Dale and Sereno, 1993), it is not yet commercially available, and may require a large number (>30) of channels of data for reasonably accurate results. Also, multi-channel MEG data collection is costly, and MEG cannot currently be collected in normal work environments, since it relies on the head remaining completely immobile during data collection, making it unsuitable at present for all but selected laboratory experiments.

In the near future, however, one can envision EEG source imaging software being used to first identify brain generators of particular interest (for example in the primary sensory cortices). Spatial filters optimally combining all available channels of data can then be constructed which can filter out brain activity not arising in the generators of interest, whose activity can then be monitored with fine time resolution in real time. Even with such advances, however, the sheer complexity of brain dynamics, plus the inherent difficulty of obtaining good spatial resolution of subcortical sources, means that the quantity of information on brain dynamics available for applied research should increase only slowly, and serious applied studies may continue to need to address open basic research questions as well.

Design/analysis considerations. The EEG is easily recorded in the laboratory, but can be problematic in operational settings. Therefore, a reasonable contingency should be considered when planning the size of a field study to compensate for lost data. In addition to loss of data because of problems with signal quality, field studies often result in unavoidable data loss for operational reasons, and therefore an extremely unbalanced data set may be obtained. Exploratory data analysis plays a major role in analyzing operational studies, and should be given as much consideration as specific hypothesis testing.

Primarily with analysis of variance procedures, many sessions are often compared depending on the design of the study, and therefore techniques for following up significant main effects and interactions should be considered. These include analyses of simple effects and various multiple comparison procedures, including Bonferroni bounds, Newman-Keuls shrinking range test, and others (Winer, 1971).

Allowances should also be made for examination of between-day variability, circadian changes, and trends which occur over the study since these are important factors to be included in the models fitted. Also, provisions should be made to examine intercorrelations among variables.

Individual differences. Individual subject characteristics of signal types need to be recognized. The type of EEG of a subject is an important variable, since individual characteristics must be considered when interpreting changes in the EEG in terms of behavioral effects (e.g. presence or absence of alpha, differences in alpha type, and alpha responsivity). Careful study of EEG recordings has shown that a variety of routes exist from waking to sleeping EEG (Santamaria and Chiappa, 1987). Similarly, the pattern of changes in the EEG spectrum between high and low alertness can differ significantly between subjects, although they may be similar for subjects with similar baseline EEG spectra (Makeig and Inlow, 1993). This fact of individual EEG differences means that averaging data across subjects will not yield as much information as will studying separately the relationship between each subject's performance and EEG. Analyses based upon individual subjects are therefore important to a greater degree than with performance data.

However, in applied studies involving technologically advanced work environments, the number of subjects available for study may be small in the first place. But even where large numbers of subjects are to be tested, experimenters should consider experimental designs including explicit study of individual differences.

Problems with recording in operational settings

Procedures to be adopted need to be carefully validated in the laboratory prior to field studies to prevent unnecessary expense and loss of data. A laboratory study simulating recording conditions of a field study as closely as possible is a useful precursor to the actual investigation although obtaining behavioral analogues of operational situations can be difficult. Emphasis should be placed on carrying out a pilot study before the main investigation to assist in planning and to identify unpredictable problems.

The EEG is relatively unobtrusive to an individual's work function and electrodes are generally worn comfortably. Some care with regard to subject comfort must be exercised if the electrodes are to be worn under a flight helmet. Developers are working on electrode systems that fit either in the helmet or the helmet liner and these are being designed to be quickly applied. Although unobtrusive, EEG, EOG and EMG electrodes can, however, cause discomfort in some subjects if worn over lengthy periods and care needs to be taken when applying electrodes.

Where recordings are to be carried out in an electrically noisy environment, care should be taken in the choice of electrodes and electrode leads, e.g., screening and short cable lengths with high impedance. As much information as possible regarding the source and characteristics of noise should be sought in advance by carrying out electro-magnetic interference (EMI) checks to identify possible recording problems (e.g., VHF communications and 400 Hz power supply in civil aircraft, proximity to transformers, etc.).

One of the most important considerations when analyzing the EEG is to ensure that signals represent activity of cerebral origin, since recordings are contaminated by many events unrelated to the brain including EOG, EMG, problems with electrodes, body movements and electrical interference. These occur in the laboratory and the problem is exacerbated in field studies. Cancellation and other automated techniques can be applied in some instances to remove the influence of artifacts. However semiautomated techniques, whereby all data is screened by software, and subsets of data outside the normal range of key variables are displayed for manual acceptance or rejection, are useful and have been found to be the most successful at some laboratories. This alleviates the need for manual screening, an extremely tedious and time-consuming activity with several channels and an insurmountable task for large experiments with many derivations.

Keep in mind that while artifacts are often a source of data contamination which has little or no relationship to the experimental manipulation, sometimes the occurrence of artifacts and unacceptable signal quality are confounded with the variable of interest. An example is that when a subject becomes sleepy, body movement will often increase in an attempt to remain awake.

In summary, it is unlikely that analysis of the EEG can be performed in a completely automated way, but careful monitoring of analysis procedures via interactive software is a useful approach.

Examples of Recordings

The EEG and EOG during a vigilance task where a subject is fully alert consists predominantly of beta and alpha activity in most individuals, with regular blinks and rapid scanning eye movements depending upon the task. When alertness becomes unstable tending towards drowsiness, periods of slower EEG activity appear, accompanied by rolling eye movements. These episodes, often referred to as microsleeps, may only last a few seconds to be replaced by alert activity (Figure 8 and 9), and missed responses are only likely to occur if a required response coincides with such an episode. The subject may then remain fully alert, or lapse further towards drowsy sleep.

The alert EEG with eyes open can be similar to early stages of drowsiness in many subjects particularly if only occipital sites are recorded (Figure 10). Typically, as a subject becomes drowsy, the alpha rhythm disappears and only desynchronous, faster activity is observed (similar to what is seen in the alert EEG). However, the EOG differs, with blinks and saccadic eye movements evident during periods of alertness and slow rolling eye movements during short drowsy periods. Changes in blink characteristics precede eye closure when alertness is decreasing.

Eye closure has a marked effect on both the EEG and EOG in the majority of subjects. Alpha activity increases, saccadic eye movements (if engaged in a task) and blinks cease. As can be seen in figure 11, there is a pronounced deflection in the vertical EOG followed by a slow return to baseline attributable to eye closure. In some subjects small irregular deflections appear in the vertical EOG with eyes closed.

Figures 12, 13, 14, and 15 show the EEG and EOG under different recording conditions. This subject has an alpha rhythm with eyes open and with eyes closed--the conditions being distinguished most easily by the EOG, although other EEG derivations may differ between conditions. Both visual tasks (reaction time and scanning) show decreased alpha and saccades.

Movement of the subject either nonspecific or related to the task can affect both the EEG and EOG recordings (Figures 16, 17, and 18).

Figure 19 shows a series of data epochs which were collected to perform topographic mapping of the EEG. Also, below each epoch is a graph resulting from the FFT of a single channel (for topographic mapping, there is one FFT for each channel). The first panel of figure 19 shows the effect of eye blinking on the raw EEG trace and on the FFT performed on the Pz data. Note how all of the frontal EEG channels are severely affected by the eye blinks, and how even at Pz, the FFT shows this effect as an increase in slow-wave activity (although it is really eye activity). The middle panel of figure 19 shows a relatively clean eyes-open EEG (no eye or muscle contamination). Note that the FFT is different (in the low-frequency range) from the previous eyes-open epoch in which eye blinks were present. The last panel of figure 19 shows an eyes-closed epoch which is also artifact free. High amplitude alpha activity can be seen in several of the EEG channels. Here, the FFT is distinct from the eyes-open FFT in that there is a large amount of power at approximately 9-10 Hz representing the alpha activity.

Figure 20 presents the topographic maps associated with the epochs in figure 19. The first panel reveals a significant amount of frontal slow-wave activity (classified as delta and theta) attributable to the eye blinks. The middle panel shows that once the eye blinks have stopped, the delta band returns to normal. The last panel reveals the clear increase in alpha activity which is expected to occur under the resting eyes-

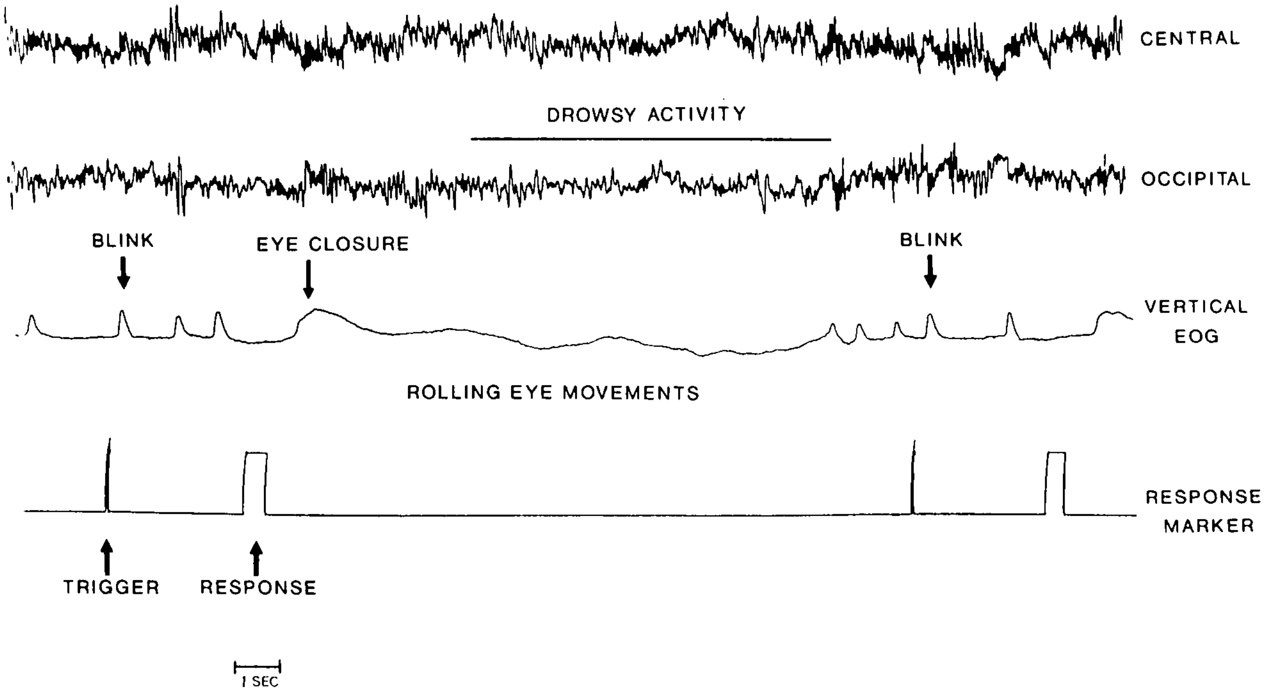

Figure 8. Activity of the brain during visual vigilance showing a period of drowsy activity.

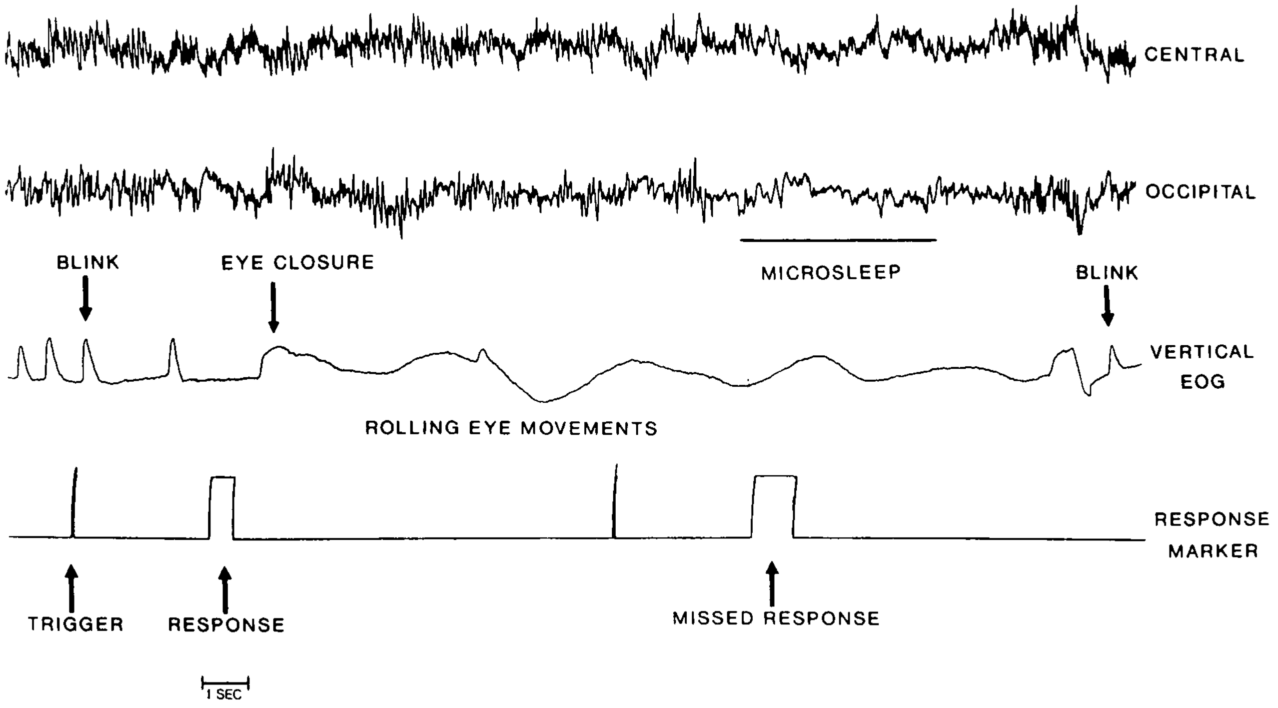

Figure 9. Activity of the brain during visual vigilance showing a period of microsleep towards the end of the example.

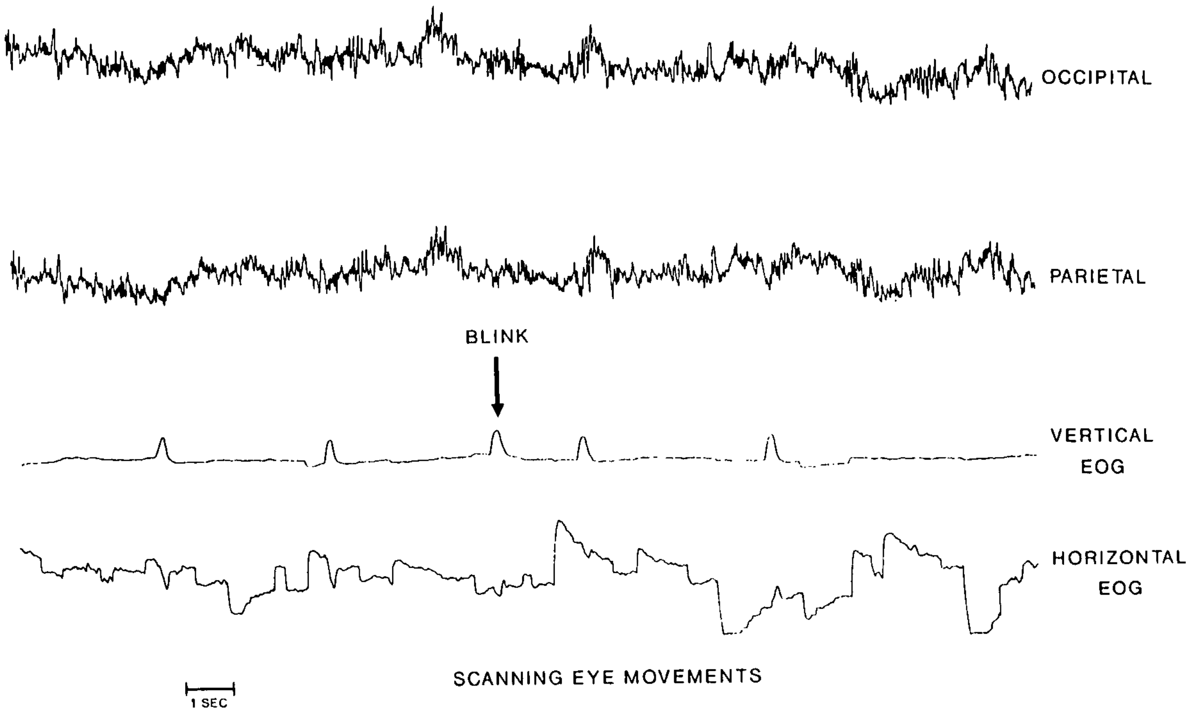

Figure 10. Visual Scanning showing alert EEG records from occipital and parietal leads. Note the clean blinks without evidence of eye movement which can be compared to figure 8.

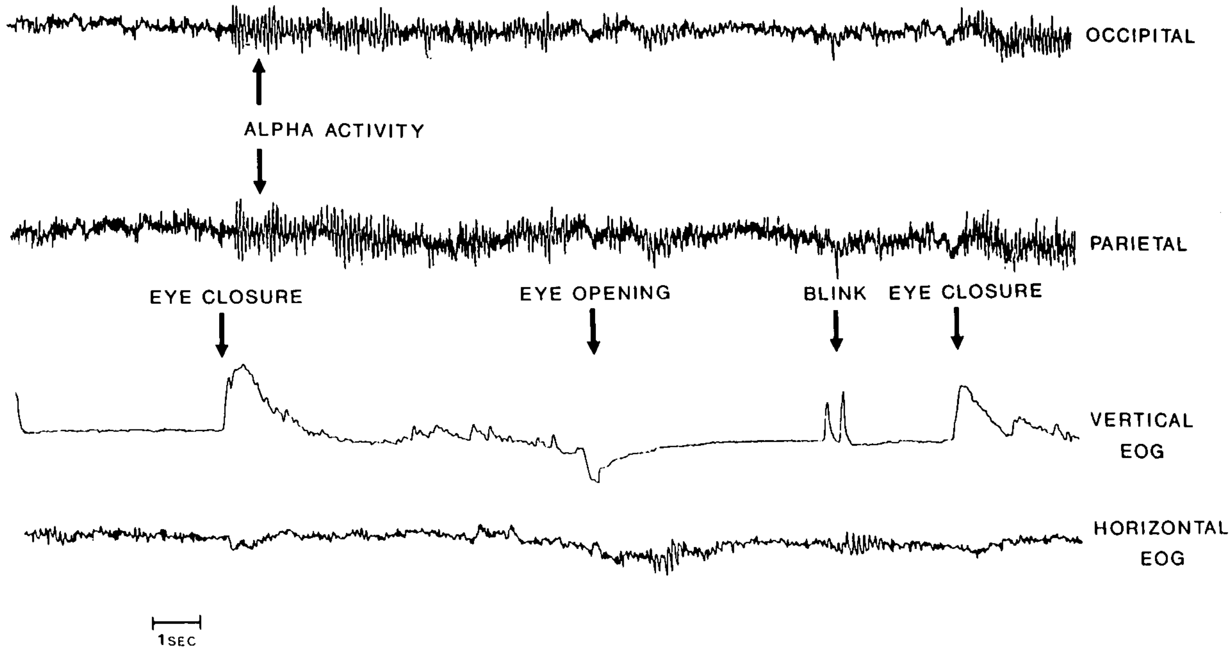

Figure 11. Effect of eye closure on EEG and EOG. Note the initialization of alpha activity that corresponds to the first eye closure and the reduction of alpha following opening of the eyes.

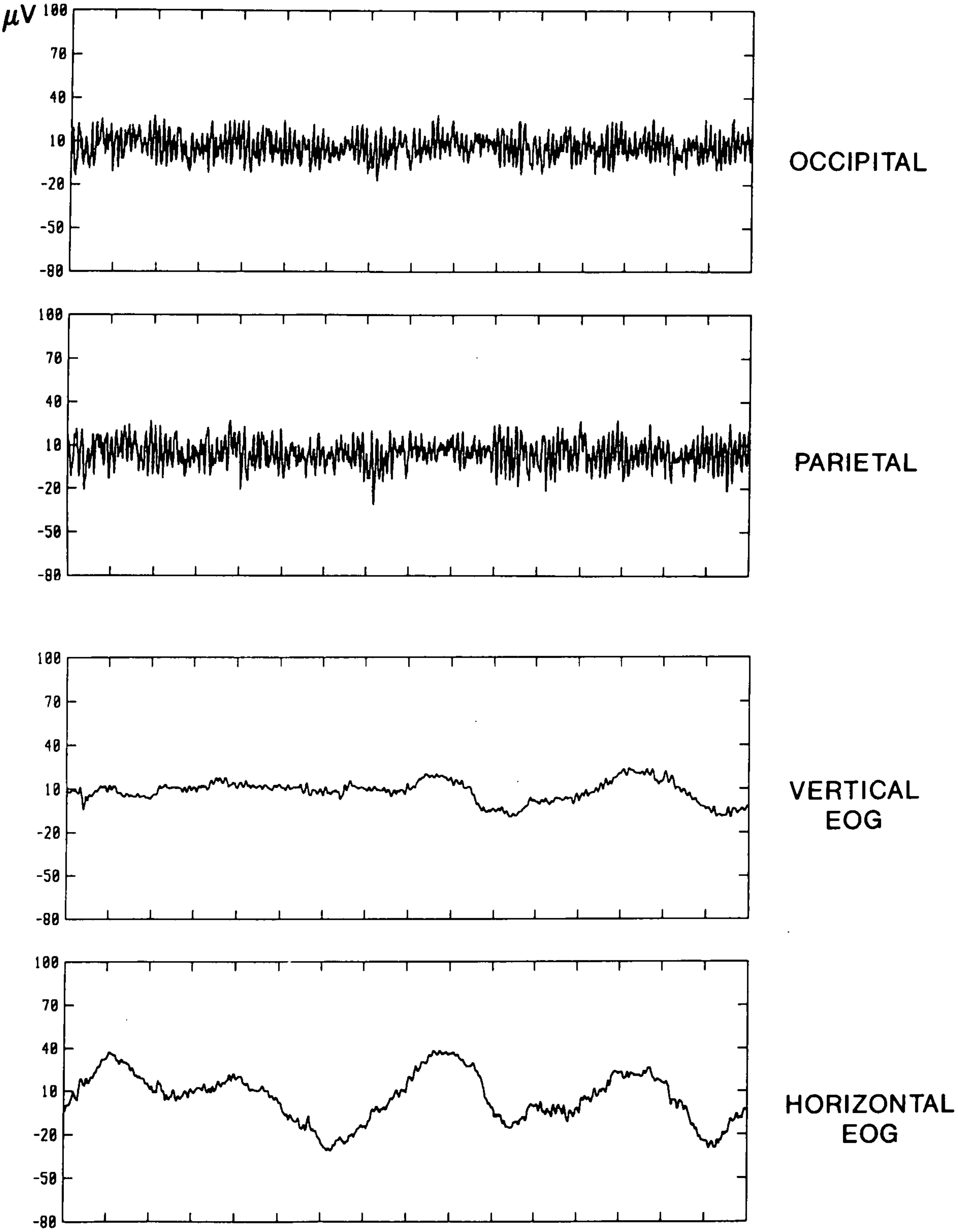

Figure 12. Eyes closed (resting), note the continuous alpha in both EEG channels and the slow eye movements in the horizontal EOG channel.

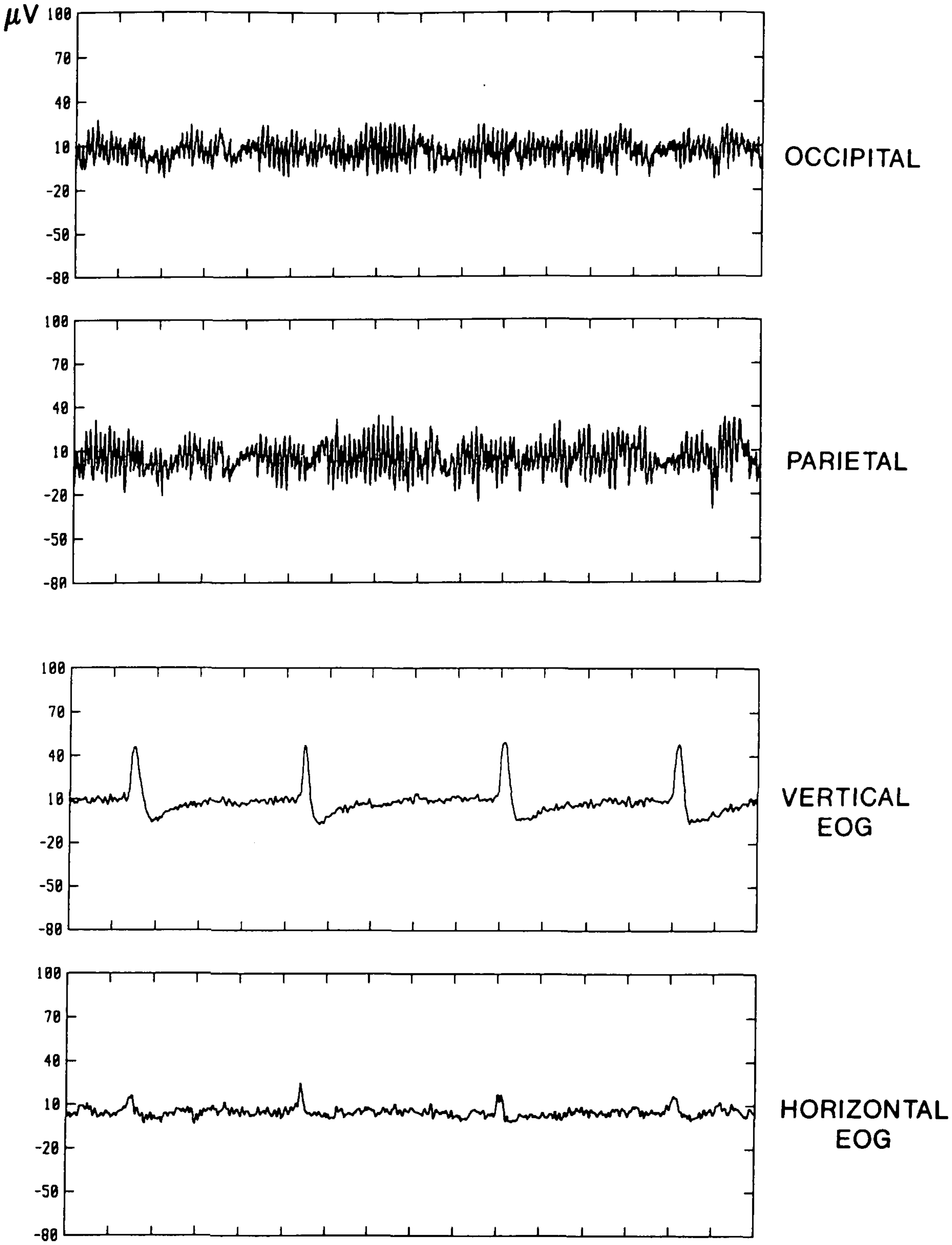

Figure 13. Eyes Open Mental Arithmetic. Note the presence of alpha in the EEG channels even though this subject is engaged in mental activity.

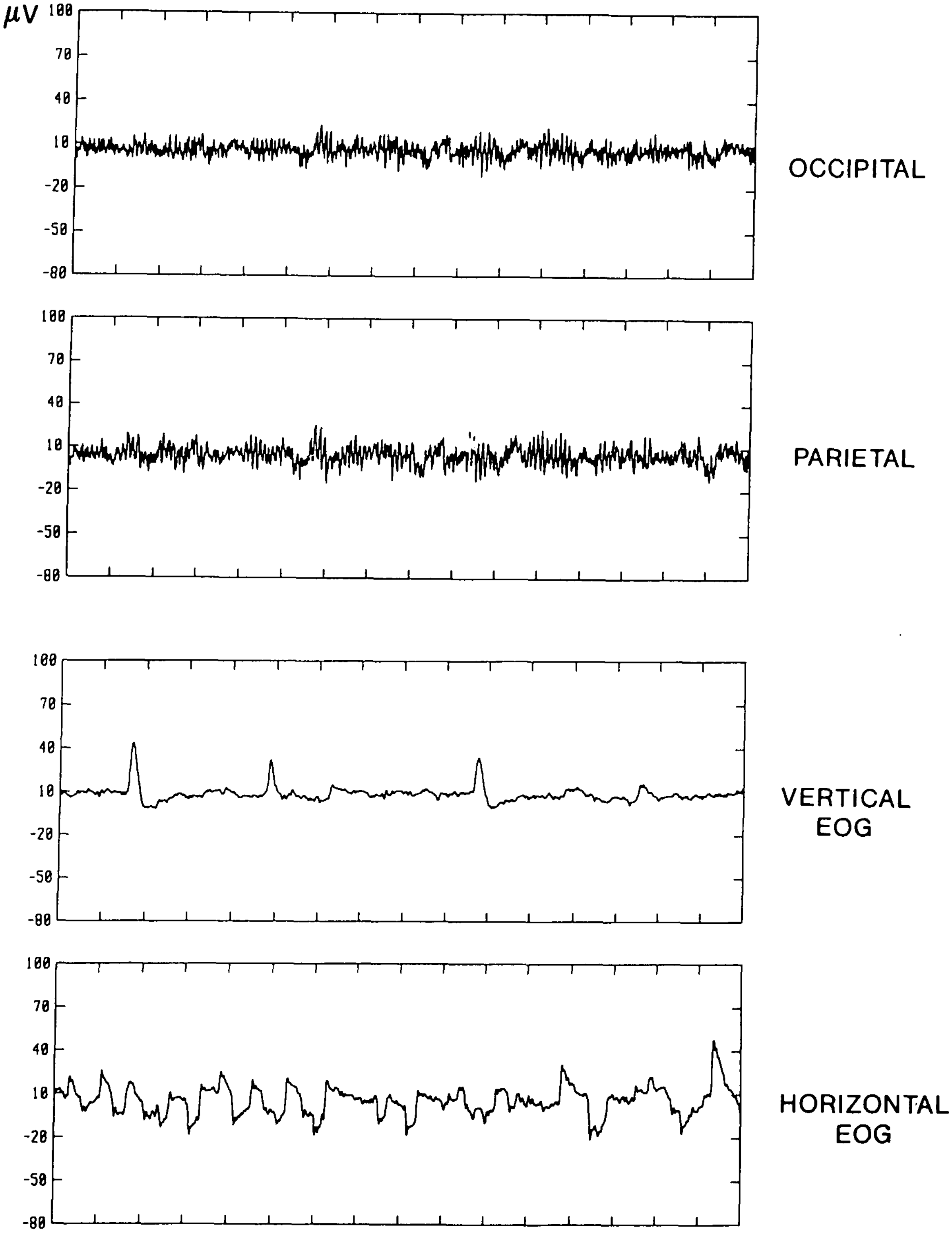

Figure 14. Reaction Time Task. This task is associated with less alpha and increased horizontal EOG activity.

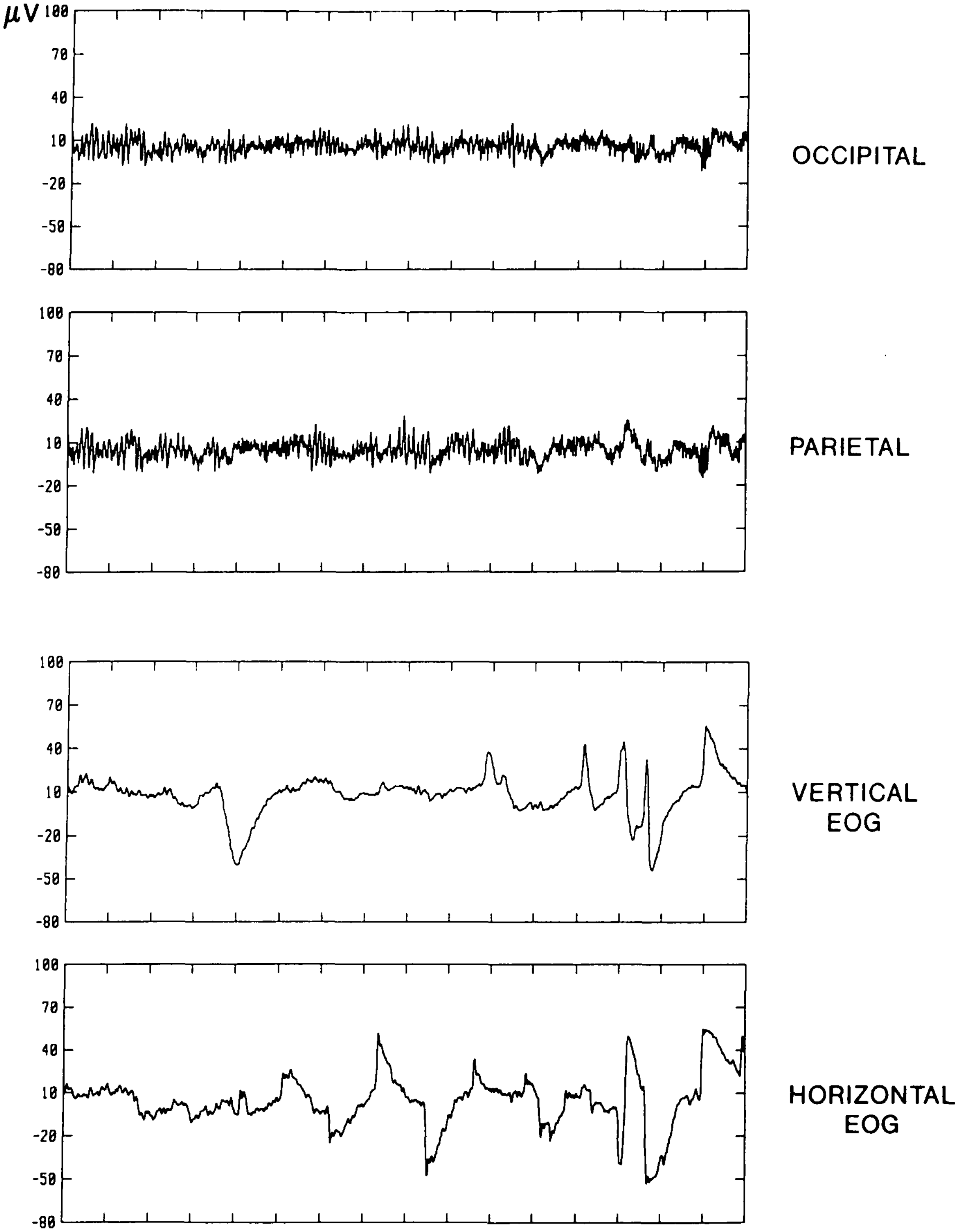

Figure 15. EEG and EOG activity during a scanning task. Note the increased EOG activity in both channels associated with this visual task. Frontal and Central EEG leads would be greatly influenced by the EOG activity.

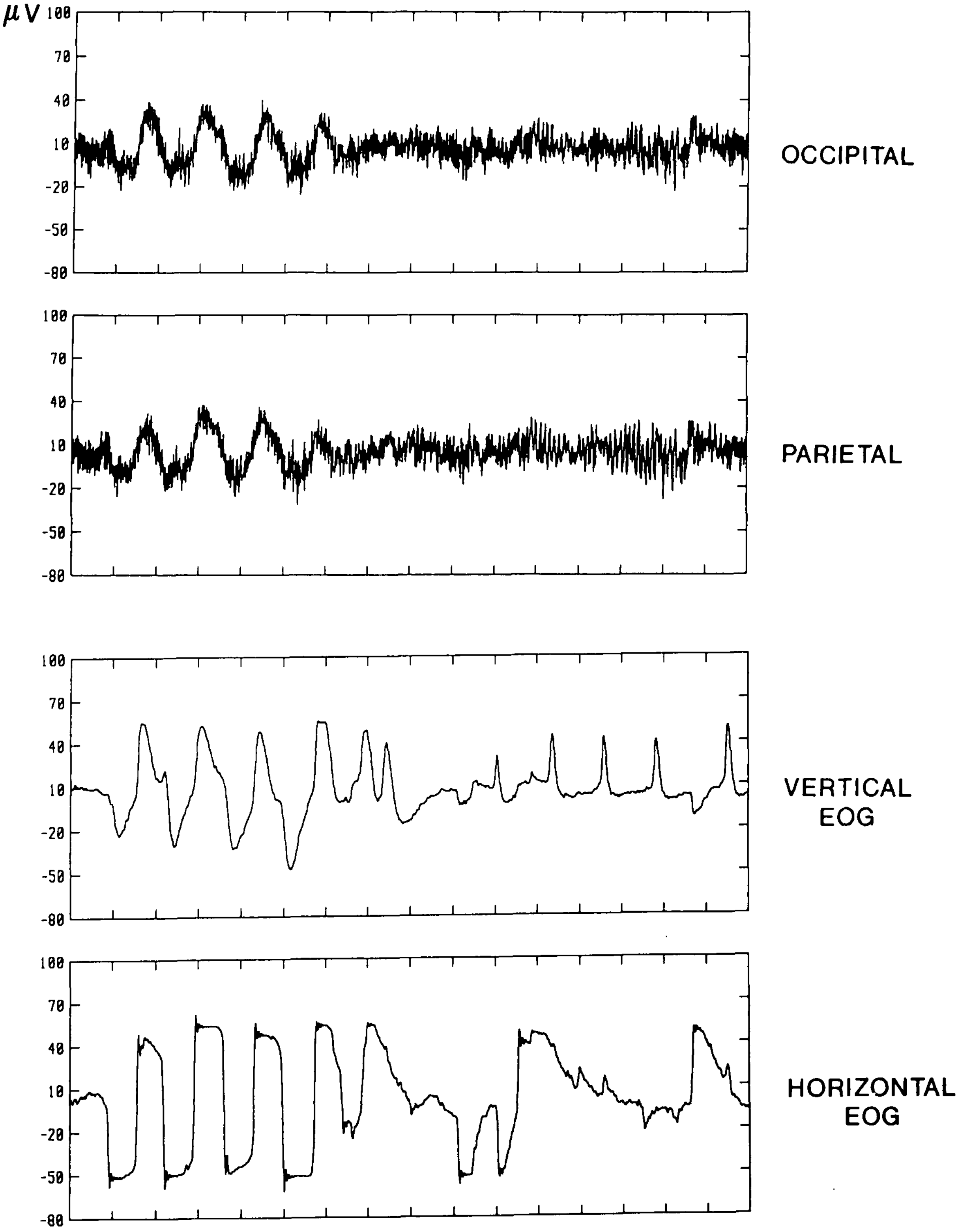

Figure 16. Movement related artifacts can be seen by increased high frequency muscle activity and large slow shifts in the signal.

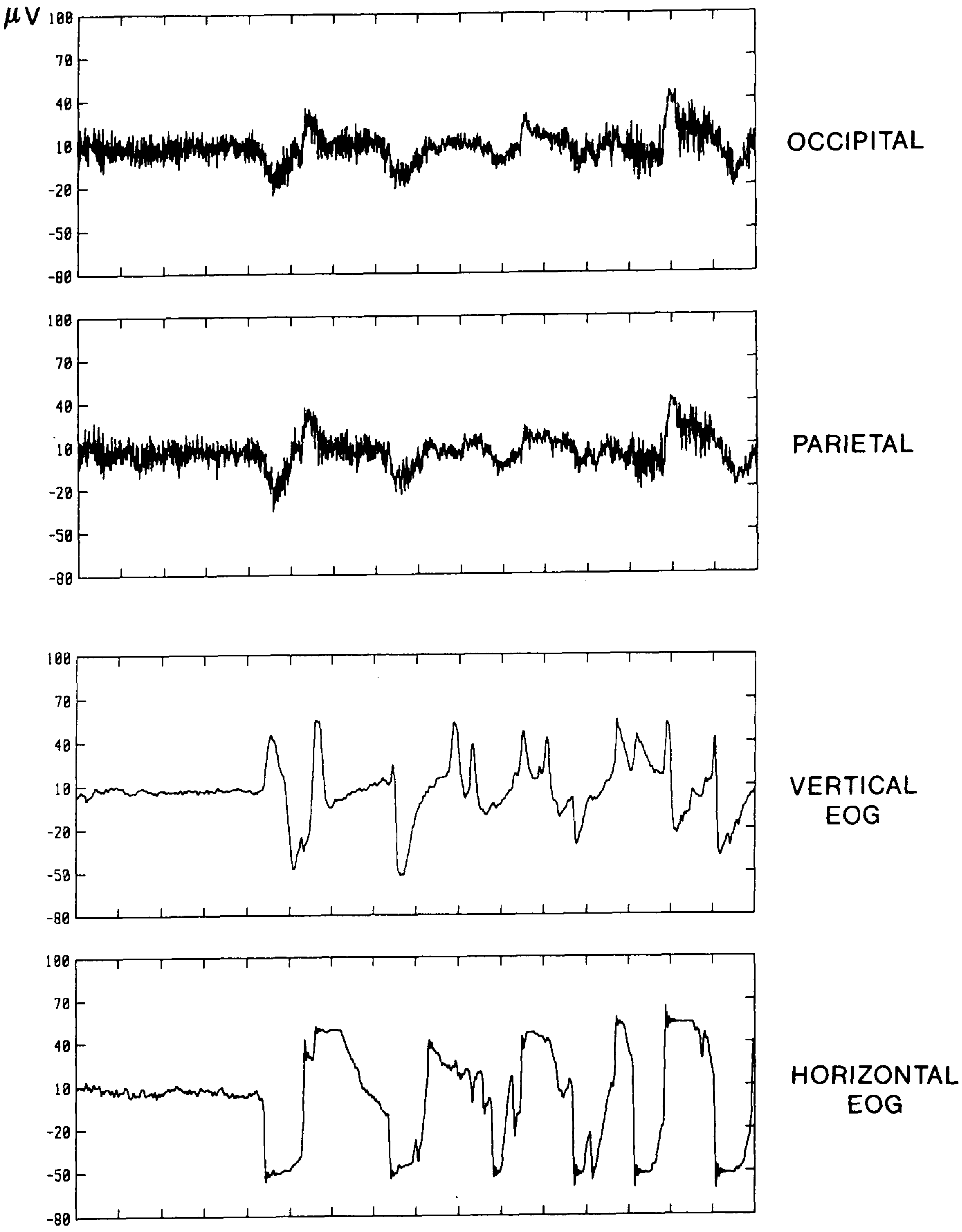

Figure 17. Movement related artifacts can be seen as large rhythmic shifts in all channels when the movements involve the entire head.

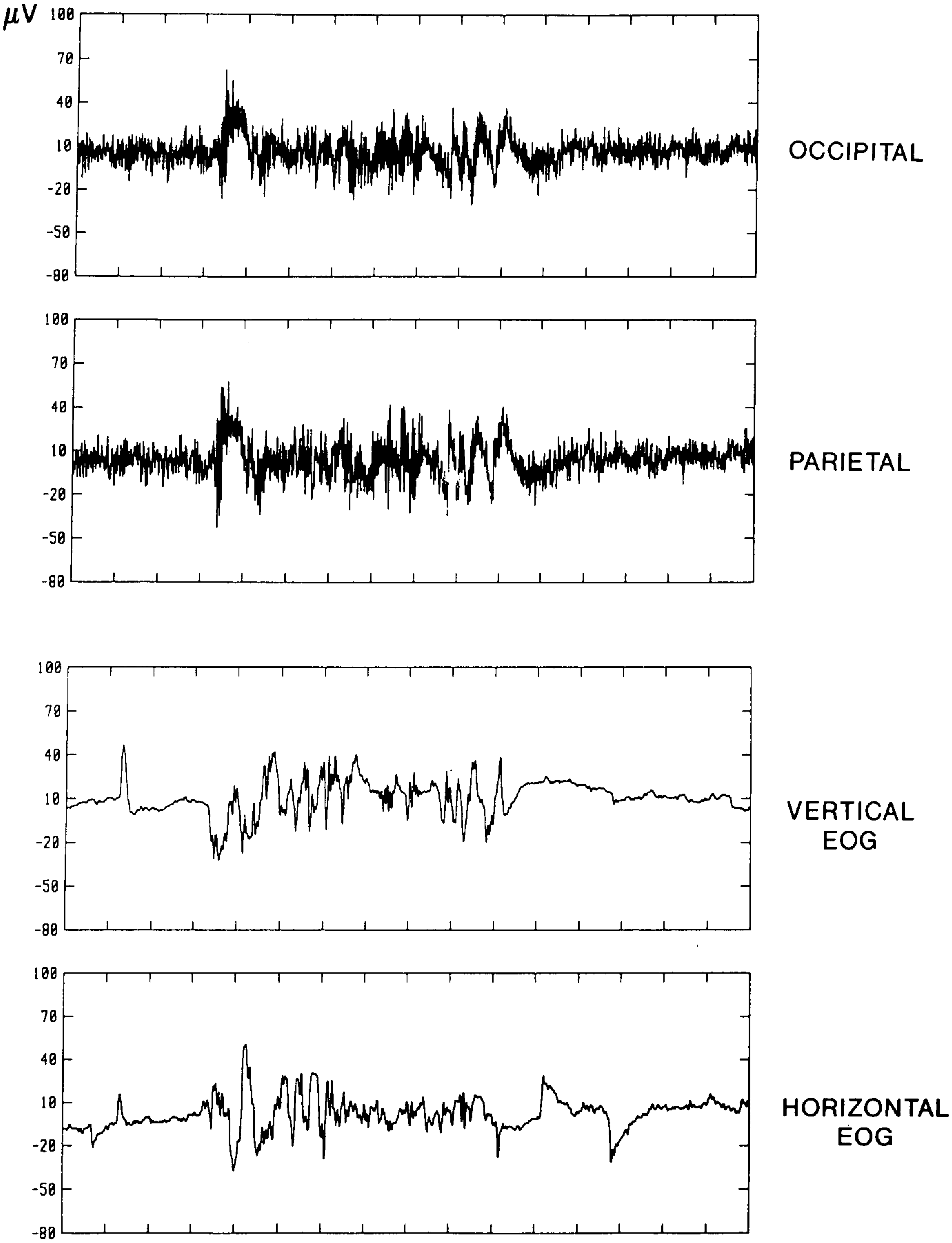

Figure 18. Movement related artifacts can be associated with burst of high amplitude, high frequency EMG that is evident all over the head.

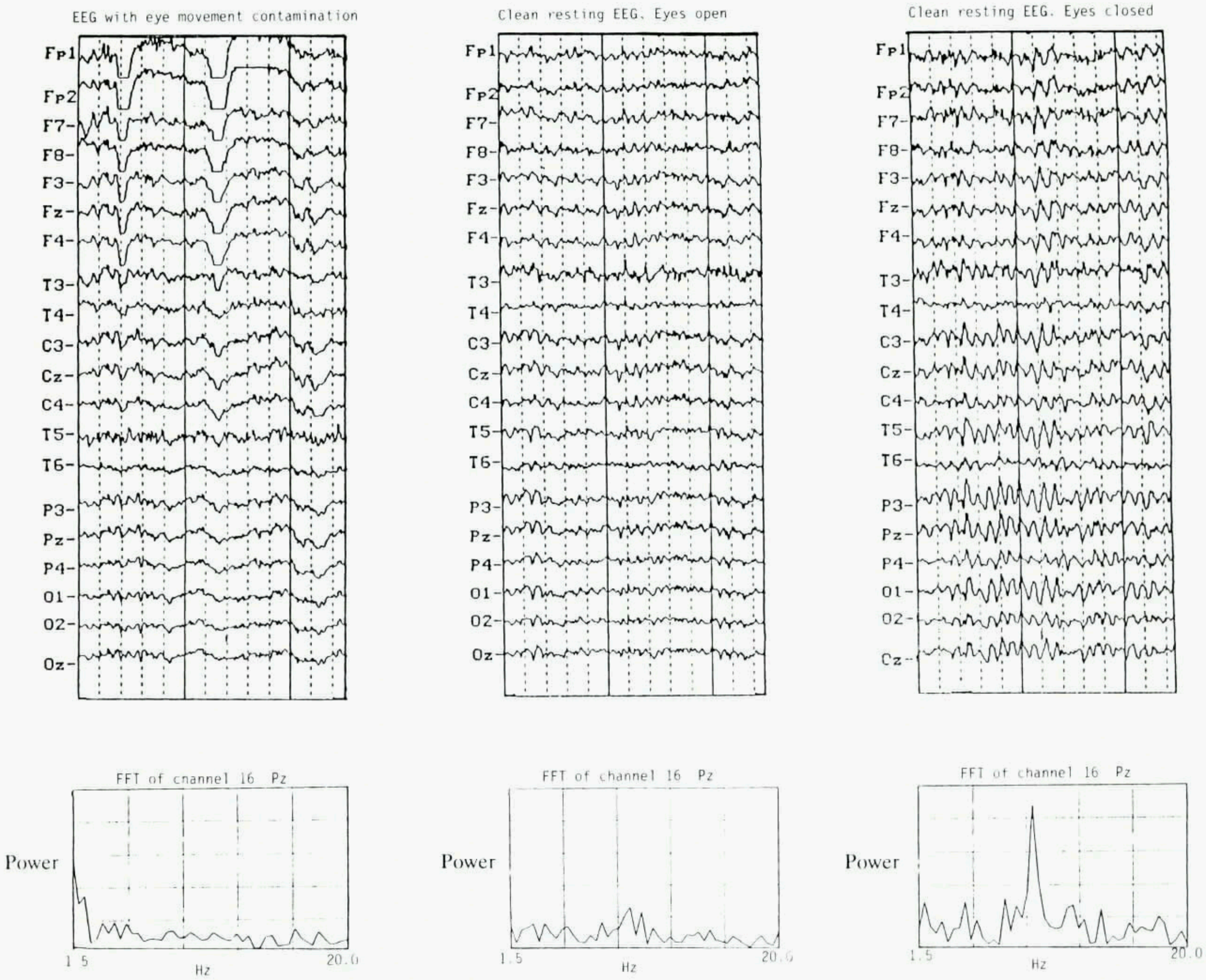

Figure 19. EEG epochs (each 2.5 seconds in length) with power spectral analyses. The first panel (on left) is EEG with eye-movement contamination, the middle panel is clean resting EEG with eyes open, and the last panel is clean resting EEG with eyes closed.

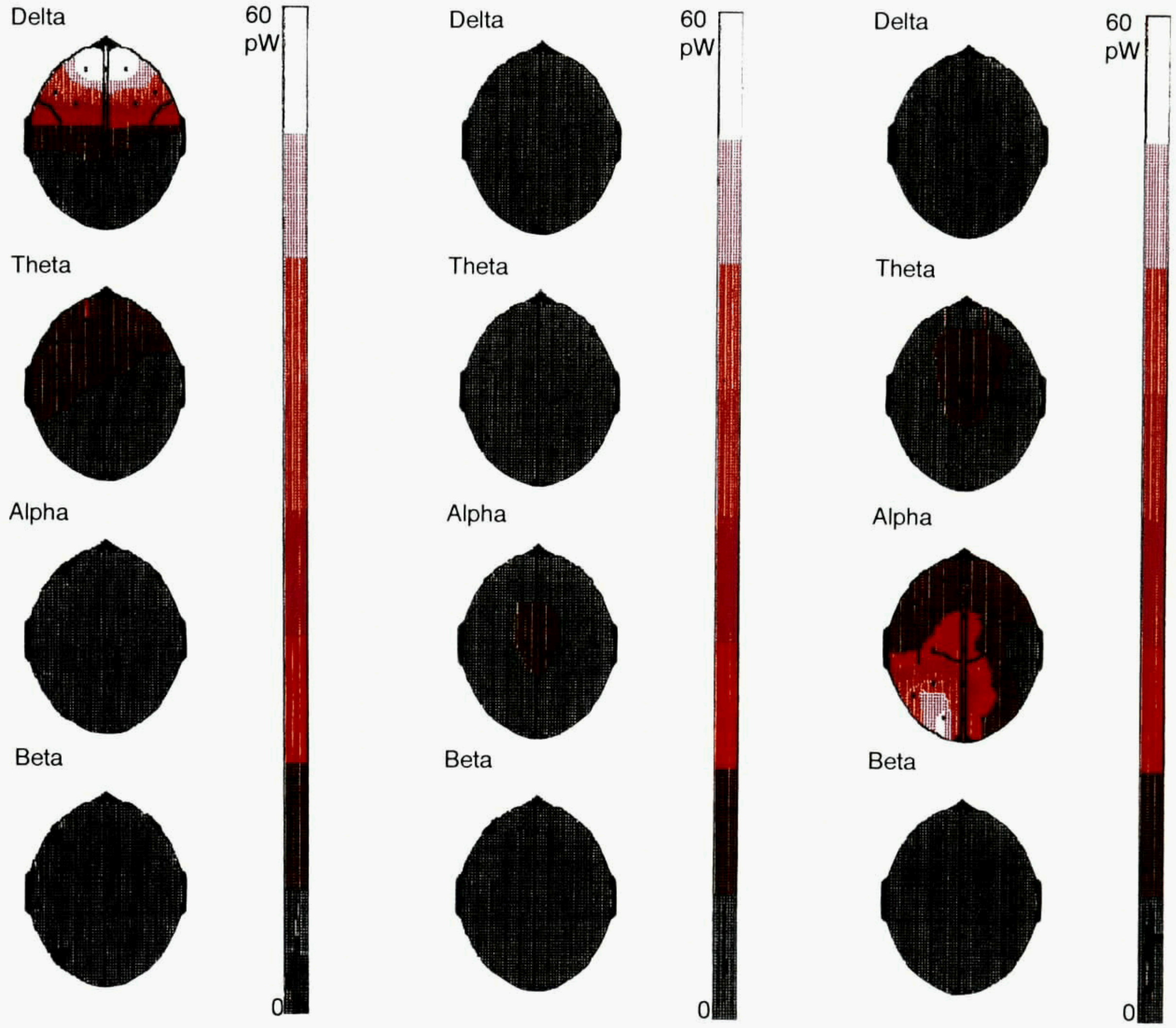

Figure 20. Topographic maps corresponding to the epochs presented in figure 19. The leftmost panel shows eye-movement contamination, the middle panel shows eyes-open EEG, and the rightmost panel shows eyes-closed EEG.

closed condition (although, in this subject there is a slight asymmetry of alpha showing greater power in the left than the right hemisphere).

Event-related potentials

General Background

Over the last decade or more, the availability of commercial digital averaging machines, and the expanding variety of brain phenomena that can be studied using the technique of averaged event-related potentials (ERPs, also called evoked potentials or EPs), have attracted more research attention in recent years to ERP research than to unaveraged EEG studies. In particular, averaged ERPs are now accepted as powerful tools for studying human sensory and cognitive processes noninvasively. However, the neurophysiological interpretation of changes in ERP measures is not simple. For example, larger potentials are not necessarily associated with more neurons being active--more highly correlated activity, or a decrease in inhibitory activity, can also result in larger responses being recorded at the scalp. Also, many brain centers centrally involved in cognition are now known to operate by modulating responses to sensory stimuli in cortex. For example, the size of the auditory N100 (N1) potential is modulated according to whether or not the subject is attending the relevant stimulus location or attribute (Hillyard and Picton, 1986). The operation of these brain systems may be seen only indirectly, for example by computing difference waves between stimuli from attended and non-attended channels as in Hillyard's selective attention paradigm.

While most studies of ERPs and performance focus on cognitive (or endogenous) ERP features, particularly the parietal P300 (P3) peak in response to anticipated target stimuli, the size and time course of auditory and visual responses evoked by stimuli not relevant to the subject's task also change according to the global state of alertness of the subject (Makeig et al., 1990). The advantage of using task-irrelevant stimuli is that they create a minimal distraction to the subject, whereas adding a secondary task, as is done in some P300 (or P3) experiments, may be much more distracting.

In order to be able to make fine distinctions between sizes and latencies of ERP features evoked under different experimental conditions, a relatively large number of responses need to be averaged. An example of a P300 waveform after 40 averages is shown in figure 21. Averaging is performed because, particularly at higher EEG frequencies, the background EEG is much larger in amplitude than the ERP. The EEG is also continuously available for analysis, whereas the size of many evoked response features declines when stimulus rates higher than one stimulus or event per several seconds are used. For these reasons, most current efforts to monitor alertness using electrophysiology rely heavily on changes in the EEG spectrum rather than on changes in ERP features.

However, ERPs to task-relevant stimuli may give specific information on cognitive processes known to be present in EEG spectral changes. It must be kept in mind that time-locking to task-relevant stimuli requires that the moments of delivery of the relevant stimuli be known precisely, and that the subject be actively involved in the task relevant to these stimuli. In many work environments this may mean an artificial secondary task must be given to the subject which may have no relevance to normal work conditions, and may interfere with job performance. The ideal situation for recording ERPs might be one in which, frequently and at precisely known times, identifiable signals requiring cognitive processing are presented to an operator in the course of their normal duties.

Equipment/recording devices

Similar considerations apply to recording evoked potentials as for recording the spontaneous EEG. However, care needs to be taken with filter settings, using pass bands as high as possible to minimize artifacts in latency estimation. For instance, it may be acceptable to use filter settings of 0.5-35 Hz for the EEG whereas the settings for P300s are slightly higher at 1.0-100 Hz and Middle Latency Responses are collected at 0.5 to 300 Hz. In addition, signal to noise ratio needs to be considered, particularly where ambulatory recordings are to be carried out.

Data collection

Signal quality may be a particular problem, especially in the field. Long latency potentials such as the CNV require the use of a long time constant amplifiers and DC electrodes, thus giving rise to trace drift which requires compensation. A suitable time-coding system for recording stimulus events with a reliable time base is required.

Data analysis

Event-related potentials are most frequently analyzed by averaging over stimuli within a task or blocks of stimuli. The averaged EPs are typically scored in terms of the latencies (milliseconds) and amplitudes (microvolts) of each of several components (N1, P2, N2, P3, etc.). Once the latencies and amplitudes have been determined, these data are submitted to analysis in standard statistical procedures, such as analysis of variance, to determine whether the ERPs were affected differently under different treatment conditions. Another method of analysis involves comparing averaged waveforms with a Principal Components Analysis (PCA) followed by analysis of variance of factor scores. There are many published articles and books which explain both of these procedures in detail.

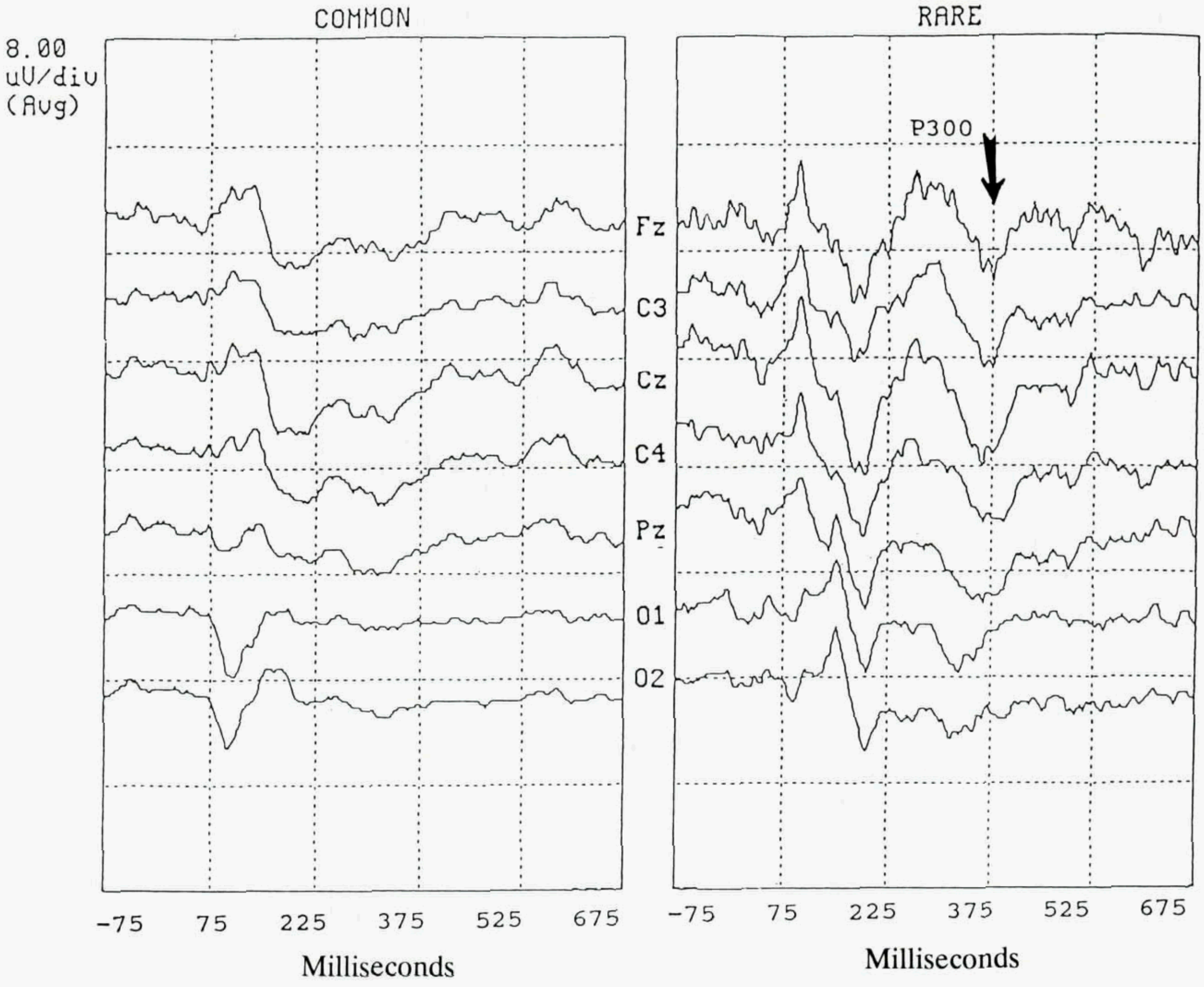

Figure 21. Wave form averages (160 common, 40 rare) for a visual P300 task. Note the absence of a P300 to the common stimuli which were not counted by the subject as were the rare stimuli.

More recently, investigators have begun to focus on single responses and variability between responses in addition to the averaged data described above. Many different methods for studying ERP features in single response epochs have been attempted (McGillem and Aunon, 1987). The problem is, essentially, to determine what portion of the EEG trial is evoked by or induced in response to the stimulus or event of interest, and what portion represents either the continuation of ongoing background EEG or new EEG activity unrelated to the stimulus or event. Most attempts at single-trial ERP analysis use a template derived from the averaged ERP waveform to separate response epochs into estimated ERP and residual EEG activity, and attempt to study changes in large, relatively low-frequency ERP phenomena such as the P300 or CNV (McGillem and Aunon, 1987). However, in the absence of independent measures of the ERPs being estimated, the reliability of such methods may be difficult to determine. Also, as mentioned above, there may be features of individual response epochs, such as changes in time-locked but not phase-locked spectral activity, which are filtered out of the ERP template by response averaging. Nonetheless, ERPs extracted from single trials or from small numbers of trials seem to be necessary in order to study dynamics of cognition, and progress in this research area can be expected to be steady, particularly when responses at large numbers of channels are available for analysis.

Appendix C
EYES

General background

Eye blink activity has been found to be at least partially modulated by visual search and visual attention. High visual demands are associated with decreased blink rates and closure durations. Eye blinks can be recorded electrically with the electrooculogram (EOG) or with optical methods. Analyzing photographically recorded blinks is very time consuming so electrical recording methods are typically used. As the eye lid slides over the eye during a blink an electrical potential is established which can be detected with standard electrophysiological methods. Small, portable recording devices make possible the collection of eye blinks from ambulatory subjects as well as from those in laboratory and simulator situations.

Equipment requirements

Standard biological amplifiers can be used to record eye blinks. The signals are typically amplified 2,000 times and are recorded with a band pass of 0.1 Hz to 100 Hz. Signals can be digitized at frequencies between 100 and 1,000 Hz. Higher sampling rates yield a finer time resolution and increase the sensitivity to small differences in blink durations.

Data collection

Eye blinks can be easily recorded with reusable electrodes or with small disposable electrodes positioned above and below one eye. The exact positioning of the electrodes is not critical which means that they can be positioned so they do not interfere with helmets, glasses and face masks. Ag/AgCl disposable electrocardiography electrodes with snap lead fasteners are easy to apply and are readily available. The infant size is recommended since their small size makes them easier to apply and position. In preparation for electrode application, the skin should be cleaned with a mild soap solution and mildly abraded to remove the outer layer of dead skin. Inter-electrode impedance of 20,000 ohms or less (10,000 to 5,000 is better) should be achieved in order to reduce extraneous noise. Shielded leads, grounded to the amplifier, have the advantage of reducing movement induced artifacts in the recordings. In order to provide for accurate analysis of the eye blink data, a time line or event markers must be available. These can be used to identify relevant segments of data during analysis.

Data analysis procedures

Blinks. Blinks are identified using one of several algorithms and typically involve detecting a change from baseline and determining if this change meets the amplitude, rate of change, and closure duration criterion for an eye blink. A moving baseline is recommended since the high pass filter allows slow shifts in the records. Using a zero volts (+/- some value) baseline will be inefficient since the EOG record will shift above and below the zero voltage level making blink detection difficult. The blink detection amplitude criteria is used to exclude small amplitude fluctuations from being labeled as blinks. The rate of change or slope parameter is established to ensure only blinks are detected and not slow potential changes such as eye movements or slow eye closures. The closure duration criteria is used to exclude short duration events such as muscle activity or movement artifacts and longer duration events such as eye closures. The typical measures of eyeblinks are blink rate, blink duration and blink amplitude. Blink morphology and blink patterns are not as uniform as some other physiological measures, such as heart rate, which results in a slightly lower rate of blink detection. Visual inspection of computer scored records is recommended as a final check. The determination of blink duration poses a problem. The return to baseline following a blink is not a good measure of blink duration since eye opening is not as fast as eye closure, sometimes the lid does not quickly return to baseline, and vision is occluded only while the pupil is covered. A useful measure of blink duration is the half-amplitude closure duration measure which is the time from the point of half amplitude closure of the blink to the same amplitude value on the ascending portion of the blink--see figure 22 below (Kennard and Glaser, 1964). Typical values for blink duration are between 70 ms and 200 ms, with 200 to 300 ms durations seen as questionable while durations longer than 300 ms are not counted as blinks (Stern and Dunham, 1990).

The reduced data can be analyzed by determining the average number of blinks and the mean blink duration over a time period of interest such as two minutes. The time segment could encompass take-off, landing or some other relevant event. Another method is to analyze the second-to-second records with regard to environmental events such as target detection in order to see the pattern of blinks relative to visual search.

Figure 23 shows eye blink data recorded from a C-130 pilot during a low-level parachute extraction procedure (LAPES). The X-axis is the time line while the Y-axis represents the blink closure duration. The temporal pattern of blinking can be seen with this type of plot. Note the regularly spaced blinks with uniform durations prior to the LAPES, the inhibition of blinking during the LAPES and the return to the normal pattern of irregularly timed blinks and irregular closure durations which is typically seen.

Eye point-of-regard. Eye point-of-regard can be measured with devices mounted on the head or devices mounted in front of the operator. Video technology is typically used and involves optically superimposing the position of the eye upon the visual scene that the operator is viewing. Eye position is

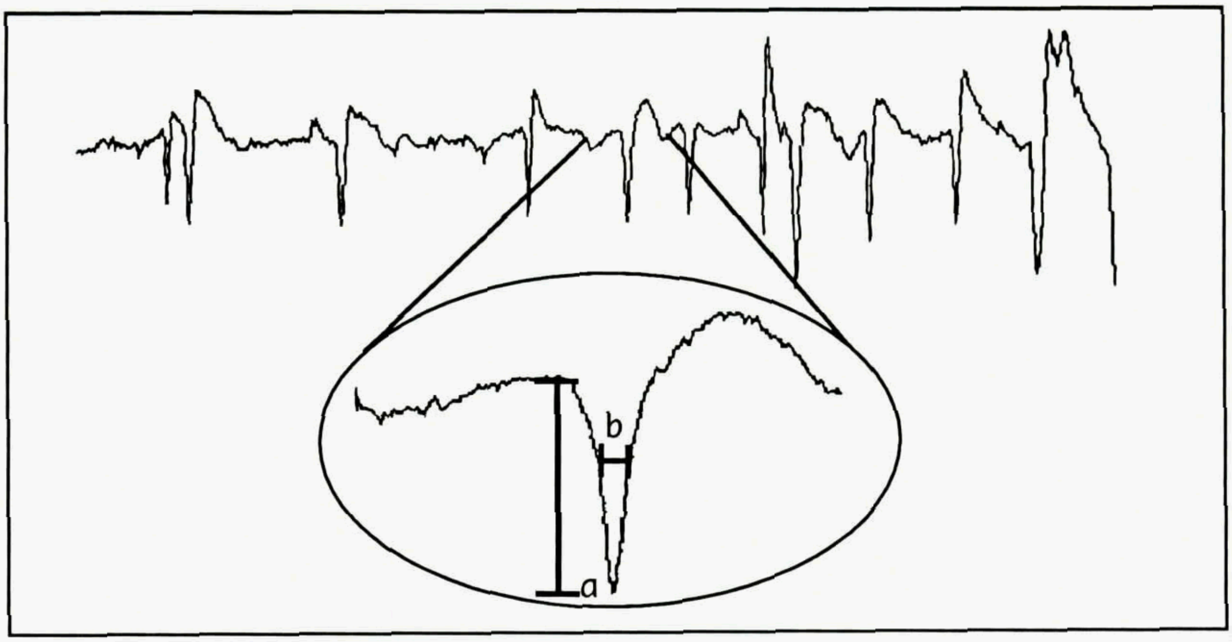

Figure 22. This is an EOG trace showing several blinks to illustrate their variability. The highlighted blink is marked to illustrate amplitude (a) and half amplitude closure duration (b).

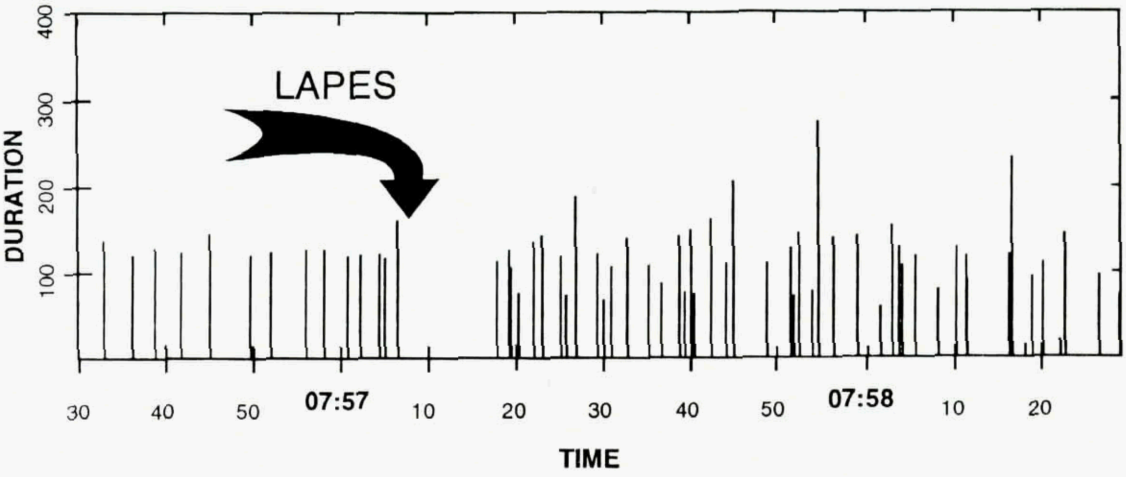

Figure 23. Eye blink data recorded from a C-130 pilot during a low-level parachute extraction procedure. Note the half amplitude duration is plotted as time with each blink represented by a vertical line. This method of displaying blinks shows the temporal pattern and closure durations in the same graph.

usually detected by corneal reflection. The portion of the scene upon which the operator is focused is indicated by a spot of light moving on the scene. Eye scan pattern and fixation duration can be determined from these records. These methods record blinks; however, the sampling rate of the video systems is not fast enough to adequately resolve blink duration. Optical calibration must be carefully done to insure that the eye position is properly aligned on the viewed scene. The resulting video tapes are analyzed by measuring eye point of regard and fixation times.

Measures of pupil diameter have been reported to change as a function of various psychological events. However, these changes are relatively small compared to the large pupil diameter changes associated with changes in ambient light levels. This poses problems when using this measure in many applied settings (see Stern and Dunham, 1990, for a review).

Appendix D
FLUIDS

General background

Analyses of endocrine changes via examination of various body fluids is one method for establishing the impact of stressors on research participants. Research shows that our autonomic system, endocrine system, and immune system are sensitive to environmental changes and other requirements. Thus, the biochemical analysis of bodily fluids can provide considerable information about the effects of stressors on human operators. In addition, biochemical analysis provides insights into the adaptive psychological and biological reactions which allow subjects to cope with work-related, environmental, and other stressors.

Typically, factor analyses of endocrine responses have focused on three relatively constant and stable factors: catecholamine, cortisol, and testosterone. There seems to be a relationship between psychological defense mechanisms and both cortisol and immunoglobulins as well, and additional research will no doubt reveal other interesting relationships between the psychological reactions and physiological responses crucial to the maintenance of adaptive homeostatic reactions.

Equipment requirements

When planning an experiment using psychophysiological methods, the first aim should be a thorough evaluation of which substances should be studied, along with an assessment of the level of analytical expertise required. In many cases, the interesting parameters can be assayed using equipment which can be operated successfully after a minimum of training and practice by skilled laboratory technicians. However, it is generally desirable to delegate the responsibility for biochemical analyses to a university laboratory, a biochemical research institute, or a commercial operation.

The primary techniques for performing fluid analyses are radioenzymatic assays, radioimmunoassays, chromatography, and automatic sampling (Grunberg and Singer, 1990). All 4 techniques require refrigerated centrifuges. Radioenzymatic assays further require a variety of equipment including a water bath, scintillation counter, and a fume hood. Radioimmunoassays require a gamma counter, water bath, and a refrigerator, and chromatography requires a chromatograph and oscillating shaker. Automatic sampling requires the sampling machine with accessories. Various levels of training and expertise are required in order to properly operate these devices so that valid assays can be performed (see Grunberg and Singer, 1990 for a complete discussion). A psychophysiologist without biochemical training is not able to perform hormonal analysis at the level of accuracy that is required for this kind of research, and it is easy to mistake high or low hormonal levels for interesting results when they are actually due to incorrect procedures.

Methods

Although there are a number of bodily fluids which can be analyzed for various constituents, the fluids which are most accessible include blood, urine, and saliva. The choice of which fluid to collect and analyze depends on what type of substance the researcher wishes to examine. Although blood is the standard body fluid for most biochemistry laboratories, in some applications, it may be better to analyze urine. For instance, when studying acute stress responses, repeated blood sampling from an indwelling catheter (beginning no sooner than 20 minutes after insertion) is the preferred approach. But, when studying chronic stress reactions, it is better to collect urine over 8-24 hour periods and analyze it for the levels of various "stress hormones" (Grunberg and Singer, 1990).

Blood. Blood consists of distinct components: plasma, erythrocytes, white cells, and platelets. One consideration when performing analyses of blood is that the level of a specific substance of interest may differ within each of these components. Another consideration is that hormones have differing half-lives which can be measured in minutes, and the fluctuations of various hormones may occur quickly. The analytical results are dependent upon the time at which the sample is drawn in relation to the sequence of secretion-action-catabolism.

Blood may be collected as a venous or capillary sample. The most usual location for collecting a sample is from a superficial arm vein using the following procedure: Clean and dry the actual area of the arm from which the blood will be drawn and apply a tourniquet above the selected site. Insert the needle into the vein, release the stasis and draw the blood using Vacutainers.

The choice between plasma, serum, and whole blood is dependent upon the analysis required. Plasma is the liquid part of whole blood, and serum is the fluid component after removal of cells and fibrinogen. If there is an even distribution of the component of interest between cells and plasma, any of the fluids can be used, but plasma is most resistant to deterioration during storage. When it is important to avoid hemolysis, then serum should be chosen. If testing for catecholamines, immediate separation of fluid from blood cells is essential and plasma should be used.

After the blood sample is collected, it is centrifuged and pipetted. If the blood samples are collected under field conditions, a field centrifuge should be used. After this, the supernatant can be removed and stored by chilling or freezing as soon as possible. No sample should be left at room temperature for more than 15 minutes. For storage, the samples may be kept in a -20° C freezer for one year, although experience has revealed that serum samples may be kept at -80° C indefinitely, as long as they are not thawed and refrozen several times.

When using blood samples, one should be aware that merely the appearance of syringes and needles may represent a potent psychological stressor for some subjects, and if the neuroendocrine response to the perception of threat affects the blood to be analyzed, an unwanted confound is added to the data. It is therefore recommended that care be taken to draw the blood samples as quickly and painlessly as possible. The whole procedure should not take more than a couple of minutes in order to keep the sample collection procedure as close to the experimental event as possible. In addition, subjects should never be kept waiting in an area where they can watch the technician draw blood from another subject. Also, if the experimental design requires that several blood samples be drawn at different intervals, the best procedure is to insert a butterfly catheter with heparin lock into the vein. This will permit the collection of repeated samples without the requirement for additional "sticks." During this process, the subject should be seated comfortably, and asked to relax for approximately 30 minutes while his/her blood pressure is monitored. Five minutes of stable values constitutes a stable baseline period.

The time of the day and the date of blood sampling should always be registered when the sample is collected. In addition, the circumstance under which the samples are drawn should be described meticulously, as well as observations about the state of the participating subject. For instance, it is important to note when the subject ate, how well he/she had slept, whether or not he/she had been performing exercise close to the sampling, etc. Since hormones reflect variations due to everyday activities in addition to changes in the stress levels under investigation, it is important to keep thorough records on the activity of participating subjects in order to be able to explain any artifacts. For some substances, it may even be necessary to have the subject refrain from eating before samples are drawn.

Saliva. Saliva analyses may prove useful for studying the levels of cortisol and certain sex hormones, but there is some disagreement about the procedures which should be used in saliva collection. The secretion from the salivary glands varies in composition from one time to another, and the relative contribution of different components in "mixed saliva" varies as a function of experimental conditions and the intensity of individual stimulation. Saliva secretion may be initiated as a consequence of stimulation, but there is also a continuous flow which takes place in the absence of any obvious stimulation. This continuous flow is considered resting secretion.

To collect saliva, a dental roll can be placed in the mouth or below the tongue after the subject has rinsed the oral cavity thoroughly. Such rolls should be processed through an elution procedure before being used for sample collection. Once the roll is saturated, it can be centrifuged to collect enough saliva for analysis. After centrifuging the roll, the supernatant may be stored by freezing until it is analyzed by means of radioimmunoassay methods.

As was the case for blood samples, the time of the day and the date on which the saliva was sampled should always be clearly recorded. In addition, it is important to keep records on the circumstances under which the sampling was performed and the physiological and psychological state of the participating subject during sample collection. However, unlike blood sample collection, there is no need for medical assistance during the sampling process.

Urine. Another alternative to blood sampling in some cases is the collection and analysis of urine. For instance, urine analyses may be used to assess adrenaline and noradrenaline values. Urine has the advantage of being easier to collect than blood, and there is no need for medical assistance during the sampling process. Once the samples are collected, they may be frozen until analyses can be performed, as was the case with blood; however, the storage times are dependent upon the specific analysis to be undertaken.

As is the case with blood sampling, urine analysis can be associated with psychological stress which may result in the appearance of higher stress levels than normally occur in the work situation under investigation. Thus, it is important to thoroughly explain all procedures to the subjects and to assure them that the data will be kept confidential.

Where urine is the medium of choice, subjects should be prescreened to determine that there are no problems with kidney function. Questions on the frequency of micturition may be sufficient. As was the case for both blood and saliva, it is important to keep records on the exact times at which samples were collected, the physiological and psychological state of participants, and the circumstances under which the samples were obtained.

When planning to perform urine analyses, the investigator should be aware that in many cases the urinary levels of components of interest are higher than those in blood and many of the urinary metabolites are more stable than the original substance in blood. Some knowledge of the derivation of urinary metabolites is essential since urine will contain metabolites derived from the central nervous system as well as from the periphery.

Analysis procedures

General. To perform analyses on blood, saliva, or urine, photoelectric absorptiometry is a relatively simple method if it is performed by a skilled laboratory technician. It involves the use of photoelectric equipment which determines the concentration of a colored solution via measurement of its absorption (that is, the amount of a specific wavelength of light that it will absorb). The results are compared to a standard solution which allows calculation of the concentration of a specific substance in the test solution. A single-cell photoelectric meter is suitable for a range of analyses. To perform photoelectric absorptiometry, there are several good commercial models are available. Their basic components consist of a light source, wavelength selector, cuvettes, and a photoelectric detection system. These systems are manufactured by Beckman, Corning, Viatron, Fisons, Perkin Elmer, and Pye Unican among others.

Radiometric methods may be used for determining the levels of catecholamines in urine. This method is, however, more complicated and is recommended only if the investigator has established a cooperative relationship with a clinical chemistry laboratory.

One should aim for relatively simple methods for measuring hormone levels when possible. Many laboratory kits for radioimmunoassay are available, but even if the kits are supplied with illustrating manuals, a partnership with an experienced technician is recommended to save time and avoid beginner's pitfalls. Also, remember that all successful clinical analyses are dependent upon continuous calibration and standardization of the methods.

Commercially available kits. If the decision has been made to analyze bodily fluids to examine the effects of a specific experimental manipulation, there are several kits available. Some of them are listed below:

Cortisol analysis:

- Amersham, "Amerlex Cortisol RIA kit".
- Dade Baxter Travenol Diagnostics, Inc. Clinical Assays, "Gammacoat Cortisol RIA kit".
- Farmos Diagnostica, "Cortisol RIA kit".
- Sorin Biomedica, "CORT CTK-125, RIA kit".
- Cortisol analysis may also be performed on Abbot's TDx instrument, Fluorescence polarization immunoassay (FPIA).

Testosterone analysis:

- Radioisoptenproduction, "125 I-Testosterone kit".
- Amersham, "Amerlex Tetosterone/Dihydrotestosterone RIA kit".
- Farmos Diagnostica, "Spectria Testosterone RIA kit".

Prolactin analysis:

- Farmos Diagnostica, "Spectria Prolactin RIA kit".
- Pharmacia, "Prolactin RIA 100".
- Behring, "RIA-gnost Prolactin".
- Sorin Biomedica, "PROLK PR, RIA kit".
- Prolactin analysis may also be performed on Abbot's IMX instrument, Microparticle enzyme immunoassay (MEIA).

Glossary-Appendix D

Blood plasma: Liquid medium in which cellular elements of blood are suspended.

Calibration: Methods of defining known relationships between input and output of a system.

Catecholamines: Organic components with endocrine and transmitter functions, examples are Adrenaline and Noradrenaline.

Cortisol: Steroid hormone having major effects on carbohydrate metabolism, salt and water balance, and inflammation. Cortisol levels in the blood can be regarded as an indication of anticipated stress experienced by the subject.

Erythrocytes: Non-nucleated red blood cells responsible for oxygen/carbon dioxide transport.

Extracellular body fluids: Fluids maintained within the body but not within its cells.

Hemolysis: Contamination of plasma or serum with haemoglobin from damaged erythrocytes.

Intracellular body fluids: Fluids within body cells.

Ph: Standard measure of the acidity or alkalinity of a solution expressed as the negative logarithm of the hydrogen ion concentration in moles/liters. Values below 7.0 are acid and above 7.0 alkaline.

Plasma: The liquid part of whole blood.

Platelets: Circulating blood element without nucleus. Active in the clotting process.

Photometry: Quantification of analytes by study of the incident light absorbance characteristics.

Prolactin: A hormone influenced by the anterior adrenal gland. Prolactin is regarded as sensitive to acute stress situations.

Prostaglandines: Family of compounds derived from arachidonic acid having a wide variety of hormone-like actions.

Radioimmunoassay: A method for measuring hormones based on competitive binding of the hormone and the radioactive hormone to antibody.

Sampling rate: Any quantity which varies with time must have a value at all times, but measurements of it can only be made at specific times. Such measurements therefore represent only a sample from the infinite number of possible values and the number of measurements made per unit of time is the sampling rate.

Serum: Fluid component after removal of cells and fibrinogen.

Spectrophotometry: Analytical method designed to measure the amount of monochromatic light absorbed by a solution.

Testosterone: Sex hormone produced in the mammalian testes and in the ovaries and adrenal cortex. Stressful conditions have suppressive effects on testosterone secretion.

Vascular bed: Network of small vessels: arterioles, capillaries, and venules.

Appendix E
HEART

General background

The recording of heart rate is relatively simple. Typically, electrodes are attached to the upper and lower part of the sternum or one electrode is attached to the upper sternum and one to the lower left side of the rib cage and a ground electrode is attached to the lower right rib cage. Since the cardiac signal is large and the goal usually is to obtain interbeat intervals, exact electrode positioning is not critical. Thus electrodes can be positioned so they do not interfere with clothing, straps, etc. The exception to this is when using impedance cardiography to index cardiac output, stroke volume, and systolic time interval, where the detection of a good Q-wave is essential to accurately measure pre-ejection period. In this case, electrode positioning should be more exact. Small ambulatory recorders are available for amplifying and recording the electrocardiogram (ECG).

Equipment requirements

Since they are widely used clinically, ECG electrodes are manufactured by a number of companies. The electrode material is typically Ag/AgCl which is non-polarizing. The electrode, electrolyte, backing, and adhesive come as a single unit. A snap lead or similar attachment arrangement is used to connect the electrode to the amplifier. Clean records are obtained if the electrode interface has a low impedance. This reduces the intrusion of unwanted signals. The skin preparation involves removing the outer layer of dead skin and removing skin oils. Both of these cause impedance between the body and the electrode. The outer layer of skin can be removed with an abrasive pad or a gauze pad rubbed on the skin. The skin oils can be removed with alcohol or a mild soap solution. Chest hair should be removed by dry shaving the area to be covered by the electrode. Care must be taken since some people are sensitive to the electrode adhesive. Repeated application to the same skin area can also result in skin irritation.

When recording from ambulatory subjects, try to avoid placing electrodes over muscles since they can cause artifacts when the subject moves. Movement of the leads across the skin can also cause artifacts. The electrode leads can be taped to the skin or shielded leads can be used with the shield connected to the amplifier ground.

In order to correlate changes in cardiac activity with performance and environmental events, a time signal or event markers must be provided. These permit the correlation of significant changes in cardiac activity with significant events in the environment.

Amplifiers

Biological amplifiers with good common mode rejection and high input impedance should be used to amplify and condition the ECG signals. The signal is amplified 2,000 to 3,000 times and is filtered with a band pass of 1.0 Hz to 100 Hz. If a high pass filter of 5 Hz to 10 Hz is used the T wave is greatly attenuated making R wave detection easier.

Data reduction

After amplification and filtering, R wave detection is accomplished in several ways. If using an analog system (such as the solid-state programming racks found in many laboratories), the ECG signal may be passed through a Schmitt Trigger which will generate an output pulse when the voltage of the ECG exceeds a certain value. Since the R-wave is the largest component of the ECG, it is a simple matter to set the detection threshold at a point where no other components of the ECG will reach it. When using a digital system (such as a laboratory computer), there are special software routines which can scan a digitized ECG in order to detect the R-wave. Special purpose devices, such as cardiotachometers, also can be used to detect the R waves and plot the interbeat interval on a chart or they can be entered into a digital computer. If a digital computer is used for R wave detection the signal should be sampled with a frequency between 100 and 1000 Hz. This yields samples every 10.0 to 1.0 millisecond--the higher rates are especially important for situations or individuals with extremely high heart rates and also for estimating heart rate variability (Mulder, 1992; Porges and Byrne, 1992; Roscoe, 1992). The large R wave of the cardiac P, Q, R, S, T complex (see figure 24) is detected by one of several methods and the R-to-R times are calculated as the interbeat interval (see figure 25). Either interbeat interval or heart rate can be used to calculate effects (Graham, 1978; Jennings, Stringfellow and Graham, 1974).

Data analysis

Interbeat intervals. The mean of the interbeat intervals can be used to characterize a segment of data. The interbeat intervals are usually scanned for extremely short and long IBIs that indicate possible artifacts in the data. Short IBIs may result from extraneous activity being detected as R waves and long IBIs are indicative of missed beats. A range of acceptable IBIs can be used to scan the data or a running average is used where a criteria of two or three standard deviations from the mean can be used to flag extreme values. If no more than 5% of the data are determined to exceed the predetermined limits, they can be safely eliminated from calculations if only mean values are of interest. But, if heart rate variability is being calculated, the data must be corrected to provide the continuous data necessary for this analysis. Missed beats can be corrected by dividing the long IBIs in to smaller segments. Mulder (1992) provides a discussion

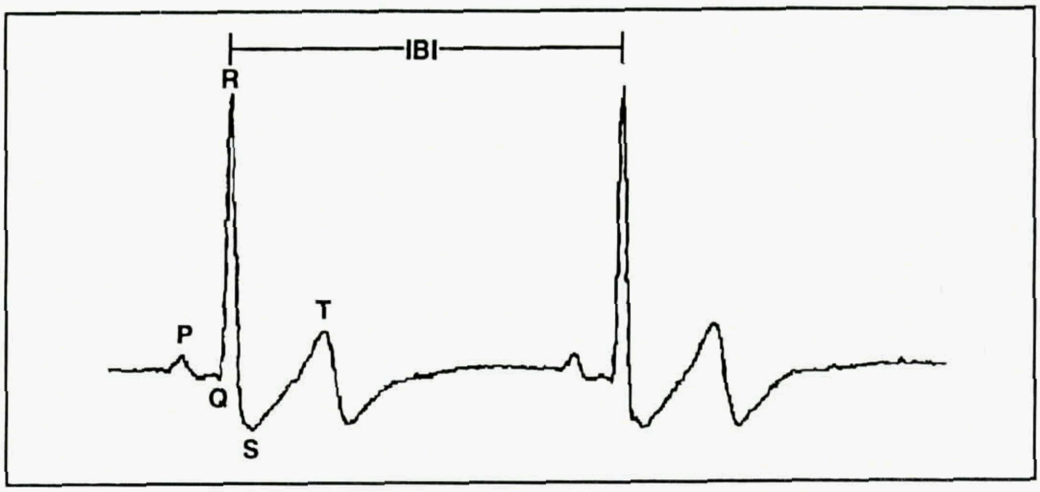

Figure 24. ECG trace showing two heart beats with the PQRST components labelled. The IBI is the time between sucessive heart beats.

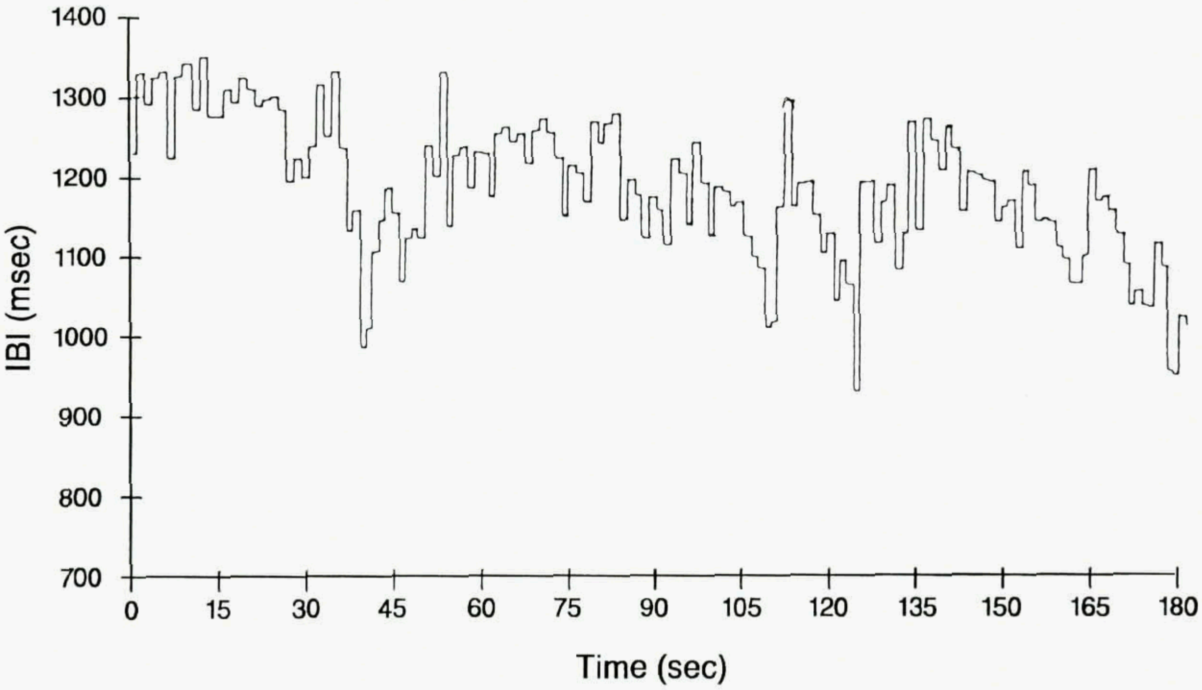

Figure 25. Interbeat interval plot. The duration of each IBI is plotted on the Y axis as a function of time. Over this 180 second period there is a decrease in the IBI (increase in heart rate), but with beat to beat fluctuations in the IBI's.

of methods for correcting ECG data. In addition to finding the mean for epochs of interest, the IBIs can be plotted and the time of significant events can be used to examine the effects on a beat-to-beat basis.

It must be remembered that cardiovascular activity is determined by a number of factors and cognitive activity is only one of them. Physical work, respiration, temperature and other factors directly impact the cardiovascular system and must be considered when interpreting the data. It is especially difficult to parcel the effects due to cognitive activity vs physical activity. One must guard against ascribing changes in heart rate or heart rate variability to increased cognitive workload when at least a portion of the effect may be due to an associated increase in physical activity. However, this does not mean that ECG data should not be collected because you may not be able to correctly ascribe the exact proportion of change to each variable. Often changes in heart rate are very meaningful and significant without the exact parceling of the contributions. It is recommended that a resting baseline be collected after a period of quiet rest. The period of quiet rest permits the stabilization of cardiac activity following changes due to physical activity involved in getting to the recording site, it provides a common condition among all subjects, and it can be used to calculate percentage changes during testing. The use of change scores from baseline is often desirable due to differences in basal heart rate among subjects.

Heart rate variability. This measure may be estimated with temporal (statistical) or frequency methods. The temporal methods use statistical representations such as standard deviation or mean square sequential differences between beats (Heslegrave, Ogilvie and Furedy, 1979). Missed beats or extra beats can be detected by using a range of expected interbeat values or by using a running average of interbeat intervals and flagging beats that are several standard deviations from this mean. Spectral analysis techniques for heart rate variability are especially sensitive to artifacts (Grossman, 1992; Mulder, 1992). For this reason short or long beats should be detected and the data should be corrected so that the heart rate variability estimates will not be erroneous (See Mulder, 1992 for a discussion of correction techniques). The use of spectral analysis has enabled researchers to decompose the heart rate variability into three components associated with different control mechanisms: low, medium, and high frequency bands have been associated, respectively, with the regulation of body temperature, the short-term regulation of arterial pressure, and with respiratory activity (see Mulder and Mulder, 1981, Mulder, 1992). An example is shown in figure 26. Spectral analysis can only be reliably applied when a homogeneous and stable recording is available with a duration of at least 3-5 minutes. This time limitation is because of the length of the slow heart rate variability cycles and the need to have several of them represented in order to estimate their magnitude. Filtering techniques permit estimation of heart rate variability within 30 seconds (Porges and Byrne, 1992).

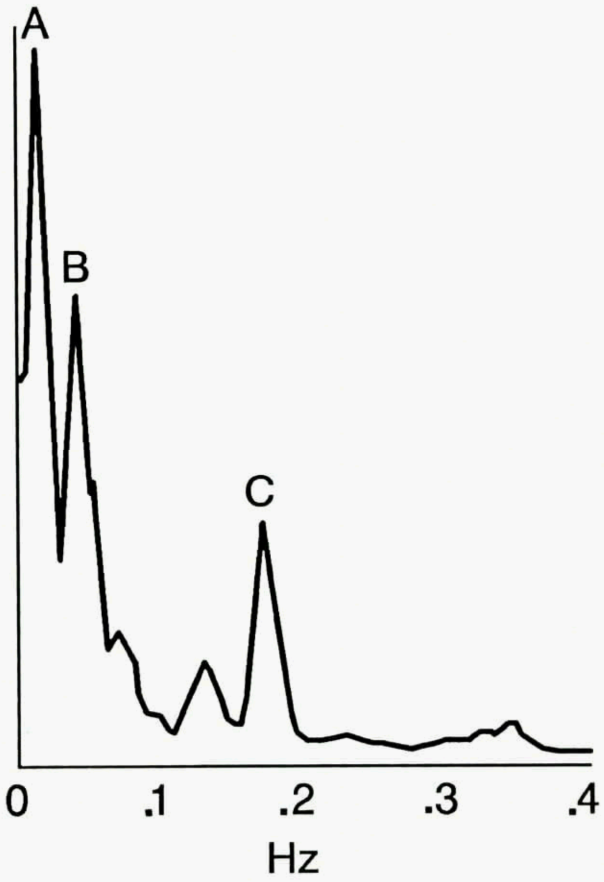

Figure 26. Plot of spectral analysis of interbeat intervals.
A- low band peak, B- midband peak, and C- high band peak.

A direct method of determining respiratory sinus arrhythmia (RSA) involves recording both the ECG and respiration. This method overcomes some of the problems with the assumptions of data stationarity and generator stability that are problems for the spectral analysis techniques. The respiration points of peak inspiration and peak exhalation are used to measure RSA. The shortest interbeat interval in the one second following inspiration and the longest IBI following exhalation are noted and the time difference between them used as RSA (Grosmann, 1992; Wientjes, 1992a).

Appendix F
MUSCLES

General background

With regard to recording muscle activity, two types of situations may be encountered in aviation physiology. The first is actual in-flight recordings and the second is ground-based recording in simulators, centrifuges or the laboratory. Measurements obtained under real flying conditions are difficult and require preliminary testing. In most cases the data are recorded and analyzed off-line; however, it can be transmitted by telemetry to more sophisticated recorders on the ground, but the signal typically must be processed off-line. The in-flight equipment has to be light and compact since the pilot has to wear it in the aircraft and be able to quickly exit the aircraft. Preamplifiers are usually built locally. The number of necessary channels is determined by the problem to be investigated and by the number of muscles studied. The EMG recording should be correlated with the acceleration encountered by the pilot because of the interaction of this parameter with the EMG (e.g., difficulties for a pilot to move his head under high and sustained acceleration). Acceleration should be recorded in at least two of the three axes, Gy and Gz, and the location of accelerometers is very important since pilot posture may significantly alter the amplitude of sustained acceleration. Accelerometers have to be worn by the pilot and placed close to the muscle or to the group of muscles being studied. Acceleration and EMG signal recordings should be recorded and simultaneously analyzed. Ideally, motion histories should be recorded and synchronized. This can be accomplished with a video recorder or any other technique of motion analysis applied to the portion of the limb being studied. Under certain experimental conditions, it may prove necessary to have an accurate record of forces generated by a portion of the limb and this can be measured with a force pick-up mounted at the end of the muscle chain.

In the laboratory, the use of reliable equipment provides conditions for signal recording and analysis which are very similar to those established for routine electrophysiology. During data collection in a centrifuge, the signal is transmitted in real time to recorders outside the gondola.

Procedure

Electrodes are placed onto the fleshy part of the muscle to be studied. A number of preliminary measurements should be taken to determine where electrodes should be placed to obtain the best signal, with the smallest background noise and interference. When this has been done, the skin has to be shaved, rubbed with an abrasive paste, and cleansed with a mixture of alcohol (1/3), ether (1/3) and acetone (1/3). Skin resistance is then measured using an ohmmeter to ensure impedances of 5000 Ohms or lower. Surface electrodes may be of various sizes; measurements on the surface of a wide motor muscle require electrodes of 9-12 mm in diameter. The size of these electrodes has to be adapted to the size of the muscle in order to minimize the energy loss. The active surface electrodes are most often made of Ag/AgCl. Electrodes are affixed to the skin by their self adhesive rims, and the cups are filled with a conductive paste commonly used for electrocardiographic recordings. Electrodes are directly connected to the signal amplifier and the quality of this signal is monitored on an oscilloscope.

Recording equipment

Prior to its recording, the signal has to be amplified and filtered. Amplifiers have to meet certain requirements regarding the number of channels, high-pass filters, low-pass filters, and the gain on each channel. These characteristics depend on the mode of analysis, and on the number and type of muscles studied, but general characteristics are listed in table 1.

The quality of the signal should be tested before the flight on an oscilloscope by having the subject perform motor movements. Many commercial oscilloscopes meet EMG recording requirements, but if preamplifiers do not feature an isolation protection barrier, it is necessary to use an oscilloscope operating with batteries, especially for preflight quality control operations. This criterion substantially restricts the choice of equipment.

Signals must be recorded using FM magnetic instrumentation tape recorders. Several parameters must be simultaneously recorded--the EMG, the force signal generated or motion-related activity, the two acceleration channels, and a time signal. Ambulatory analog recorders can be used if the recorder has to be worn by the pilot, but if the experiment is carried out on a centrifuge, or if signals can be transmitted to the ground, a larger selection of recorders is available. All-digital recorders should be selected since they have a substantially higher signal to noise ratio and lower distortion than analog recorders. The recording system must have a bandpass for EMG data up to 1.5 kHz and good servo control of the tape speed rotation if it is an analog recorder.

Signal analysis and processing

As explained earlier, the type of analysis and signal processing depends upon the experimental conditions and on the questions to be answered. The analysis of generated force, or recruitment of a muscle or group of muscles during a flying task involves collecting and integrating the EMG signal. There are two possible ways to perform the integration: 1) integration of the corrected signal in each muscle burst--this parameter will be quantified by dividing the integration of the electrical burst by its duration; and 2) integration of the muscle activity in five second periods over the entire recording time--this quantifies the level of excitation of the muscle. If the equipment has been previously calibrated in the laboratory, it can be

Band pass (at - 3dB)	:5 to 1500 Hz
Input impedance	:> 12 MΩ
Output impedance	:10 Ω
Noise level	:< 5 μV
Gain control	:1500 to 3000
Common mode rejection ratio at 50 Hz and 400 Hz	:90 dB

Table 1. General characteristics of an EMG pre-amplifier.

read directly as a measure of the generated force, or compared to the recruitment of agonist or antagonist muscles.

In the context of the analysis of EMG parameters of peripheral fatigue, the variations in the frequency components of the electrical signal are used. Using the Fast Fourier Transform (FFT) technique, one can study the time course of the mean spectral frequency, reflected by the mean power frequency (MPF) (Gerdle and Fugl-Meyer, 1992). Among the other relevant parameters, changes in amplitude of the electrical signal using the root mean square (RMS) is a good reflection of the level of discharge of motor neurons. Various signal analyses are currently performed on a computer after the data has been digitalized. Software are usually designed and written by individual laboratories.

Examples / Illustrations of the use of EMG as a tool in aviation physiology

There are many examples of the use of EMG as a tool in aviation physiology. The only limit is the experimenter's imagination. There are two situations where EMG is widely used. The first is the analysis of complex tasks under load. Changes in the force generated by limb segments or groups of muscles which are inaccessible for direct measurement on an ergometer can be studied during flying tasks. It is also possible to analyze the motor and muscle recruitment strategies used to accomplish the assigned task (figure 27). The second is the recording of EMG parameters of muscular fatigue during flight. There is, indeed, a close correlation between peripheral fatigue, characterized by reduced contractile performance for a given motor task, and the shift toward low MPF frequencies of the EMG spectrum. This correlation, whose actual mechanism is controversial, is an efficient way of defining the occurrence of muscular fatigue during motor tasks on the basis of electrophysiological criteria (figure 28).

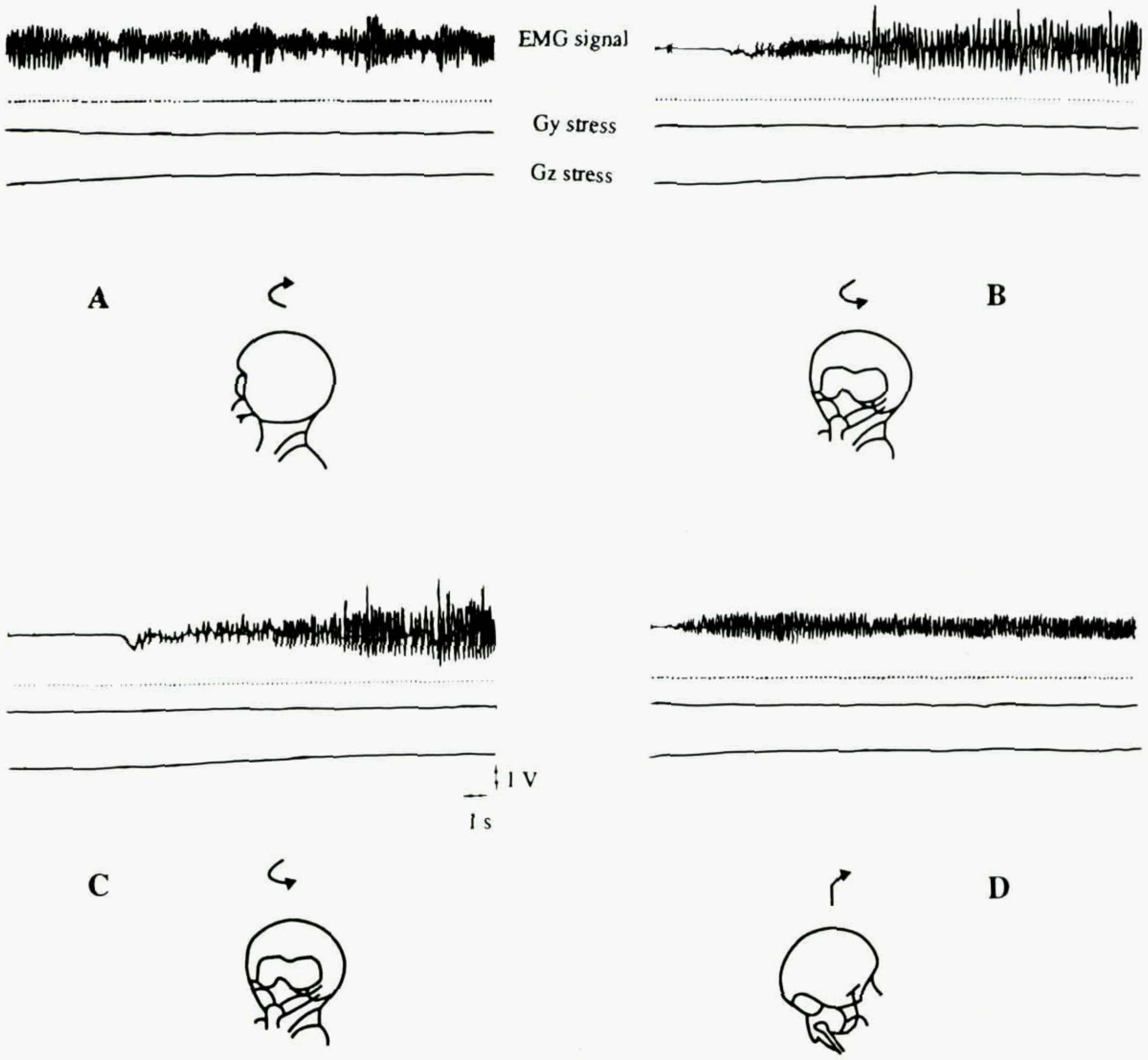

Figure 27. Patterns of EMG signal of right trapezius muscle while performing 4 flying maneuvers during sustained +Gz. (form BIGARD et al. unpublished data).

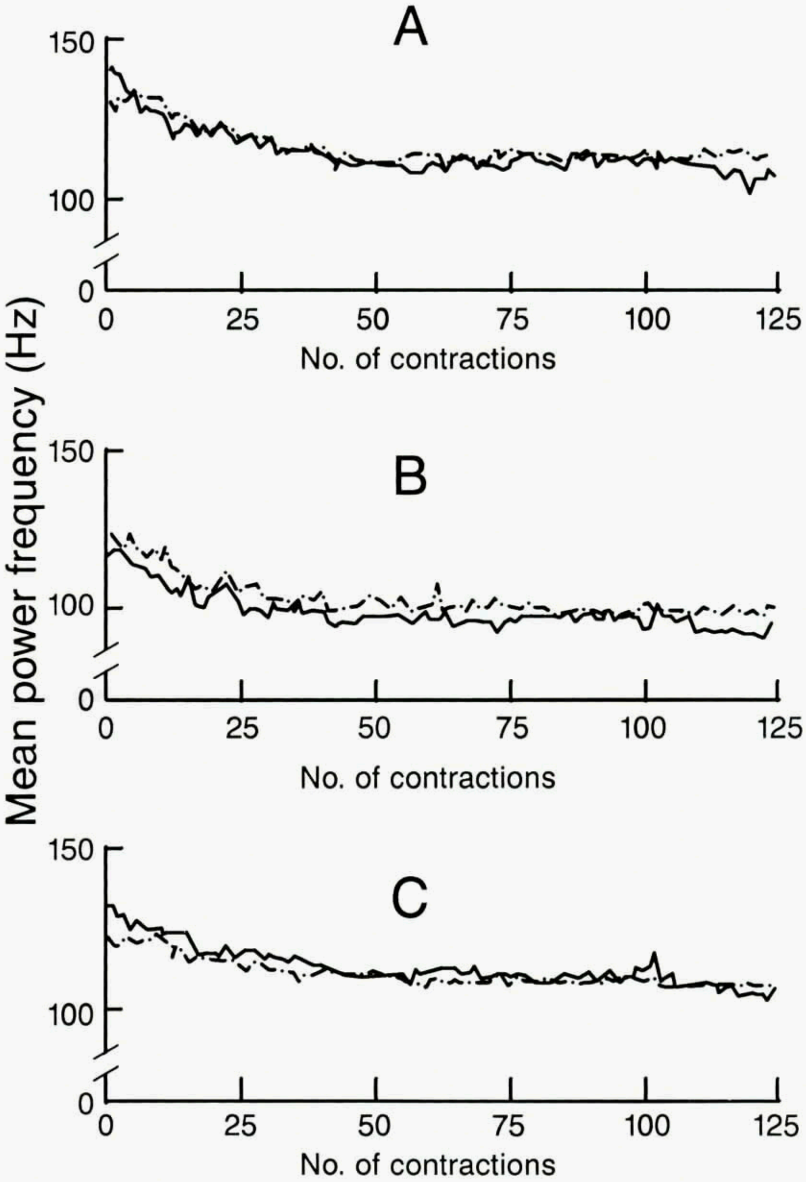

Figure 28. Relationship between number of contractions and the mean power frequency of the EMG of three different muscles.

a - Gastrocnemius Medialis
b - Gastrocnemius Lateralis (from Gerdle B. et al., 1992)
c - Soleus

Appendix G
RESPIRATION

General background

The collection of respiration data can be used for a variety of purposes which include the evaluation of work demands, stressor effects, and energy expenditure. While respiration is not examined as frequently as many of the other psychophysiological measures, the collection of respiration time and volume measures can provide useful information.

Method

Respiratory time and volume parameters. Respiration can be measured noninvasively via inductive plethysmography. This technique provides sufficient precision with regard to respiratory time and volume parameters, is easily applied, and does not interfere with the natural breathing pattern (see Wientjes, 1992a). This technique measures the separate motions of the rib cage and the abdomen. Respiratory volume changes are estimated on the basis of a model that describes the chest wall as a system that moves with two degrees of freedom (Konno and Mead, 1967). Thus, the volume of air that is displaced during each breath is estimated on the basis of the circumference changes of the rib cage and abdominal compartments. Because their relative contribution to the total volume displacement is different among different individuals, rib cage and abdomen are considered to have variable gains. These gains are determined during a calibration procedure. A number of different calibration techniques have been developed (Chadha et al., 1982; Gribbin, 1983; Morel, Forster, and Suter, 1983) that employ a calibration session during which the subject either is breathing with a fixed and known volume, or during which tidal volume is simultaneously measured by means of a pneumotachograph or a spirometer. The rib cage and abdominal gains are estimated by means of multiple regression. The general model describing the estimation is:

$$\text{Volume} = xRC + yAB + e,$$

where RC and AB refer to the rib cage and abdominal signals, respectively, and the coefficients x and y are the gains for these signals. After proper calibration, measurement of rib cage and abdominal circumference changes provides a reasonably accurate estimation of the time and volume components of respiration (see Wientjes, 1992b). In order to prevent slipping of the bands, they may be secured with an elastic vest (Bandafix).

End-tidal pCO_2. Often, it is important to assess whether the observed respiratory changes correspond to changes in metabolic processes. For this purpose, end-tidal pCO_2 may be monitored. A reduction of end-tidal pCO_2 indicates that ventilation is in excess of metabolic requirements (hyperventilation). End-tidal pCO_2 is measured via infrared analysis of the expired air (capnography). The sample tube of the capnograph is attached to an open face-mask, using a sample flow rate of 500 ml/sec. Before measurement, the capnograph should be calibrated with medical calibration gas. The pCO_2 curves should be visually inspected in order to ensure that only respiratory cycles in which the pCO_2 waveform reaches a distinct end-tidal plateau are included in the analysis.

Transcutaneous pCO_2. Recently, new techniques have become available, employing transcutaneous measurement of arterial pCO_2 by means of a heated electrochemical sensor. The output voltage of the sensor is proportional to the logarithm of the CO_2 concentration in the skin tissues. Heating the sensor to temperatures up to 45° C causes vasodilatation of the capillaries in the skin and arterialization of the capillary blood. Therefore, the CO_2 concentration in the skin tissues is assumed to be representative of the arterial pCO_2. In vivo studies have shown that the between- and within-subject correlations between arterial and transcutaneous pCO_2 vary between 0.85 and 0.99 (Cheriyan et al., 1986; Mindt et al., 1982; Pilsbury and Hibbert, 1987; Wimberley et al., 1985). The main problem with this method is caused by its response characteristics. Dependent upon the sensor temperature, the time lag of the response of the sensor to a change in arterial pCO_2 may range between 30 sec and 2-5 min (Mindt et al., 1982; Pilsbury and Hibbert, 1987). On the other hand, this method has been shown to be very useful for ambulatory monitoring of pCO_2 (Hibbert, 1986; Pilsbury and Hibbert, 1987) and for application during applied studies. Its reliability and its value for research purposes, however, remain to be assessed precisely.

Data analysis

Respiration may be analyzed on a breath-by-breath basis by determining the respiratory time and volume components and end-tidal pCO_2 for each individual breathing cycle (e.g. Wientjes, Grossman and van der Meijden, 1988). The classical analysis of minute ventilation (MV) into tidal volume (VT) and respiration rate (RR) may be employed (MV = VT x RR), but MV may also be decomposed into components that reflect different aspects of central respiratory regulation: MV = VT/Ti x Ti/Ttot (see figure 29).

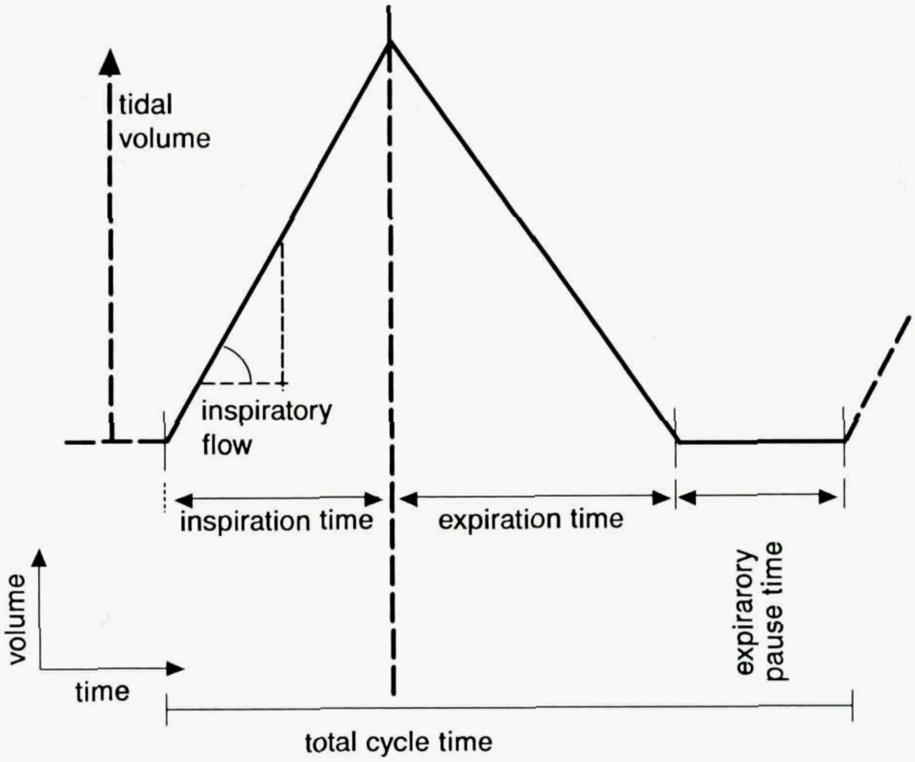

Figure 29. The decomposition of minute ventilation into the components of central respiratory regulation.

Here, Ttot is the total duration of the breathing cycle (i.e. the inverse of RR). Ttot includes the inspiratory time (Ti), the expiratory time (Te), and the expiratory pause time (Pe). VT/Ti and Ti/Ttot are both linked to different aspects of central respiratory control. VT/Ti ('mean inspiratory flow rate') reflects the strength of the central inspiratory drive, and Ti/Ttot ('duty cycle') reflects the periodicity of the timing mechanism (Milic-Emili, Grassino and Whitelaw, 1981).

Appendix H
TEMPERATURE

General background

Temperature data are often collected in studies of circadian rhythms or in investigations in which personnel will be exposed to conditions of heat stress and/or heavy physical work. Measurement of physiologically relevant temperatures refers to the registration of the temperature of the body core and that of the skin. Body core temperature is thought to reflect: 1) the temperature of the central body tissues, and 2) the temperature of the blood flowing through the heart to the brain (thus directly influencing the temperature of the thermoregulatory centers in the hypothalamus). Skin temperature can reflect: 1) the local skin temperature at the measurement site, and 2) the average temperature of the body shell (the outer tissue layer).

Both types of temperature measures may be useful in studies evaluating environmental (climatic) stress, but they should be accompanied by measures of climatic parameters such as air temperature, air humidity, wind speed, and radiation. Although these additional parameters will not be dealt with here, the reader is referred to ISO 7726 for further information.

Method

Measurement sites. Temperatures, representative of body core temperature to different levels, can be measured in the esophagus, in the rectum, on the tympanum, in the auditory canal, in the gastrointestinal tract, in the mouth, or in the urine. For both field and laboratory studies where body temperature changes are less than 2° C hour^{-1}, the measurement of rectal temperature is the best compromise between accuracy, work interference, and physical annoyance of the mentioned methods. The (electrically insulated) sensor should be inserted 10 to 12 cm, beyond the rectal sphincter and this depth should be maintained (e.g. by affixing a bead on the sensor which holds it behind the sphincter). For faster changes in core temperature the esophageal temperature should be measured, as this site shows less delay in following temperature changes of the blood flowing through the heart.

Skin temperature varies widely over different parts of the body, and this variation increases in colder climates. For determination of average skin temperature, simultaneous measurements of several sites is advised. In the heat, when only one sensor is available, the temperature of the upper arm or thigh should be measured. Preferably, at least four ($T_{skin}=.3\,T_{chest}+.3\,T_{arm}+.2\,T_{thigh}+.2T_{calf}$) and in the cold up to 14 skin sites should be measured ($T_{skin}=1/14 \bullet \Sigma\, T_{local\ skin}$) (see figure 30). An overview of several aspects of the mentioned measuring sites and methods is presented in Table 2.

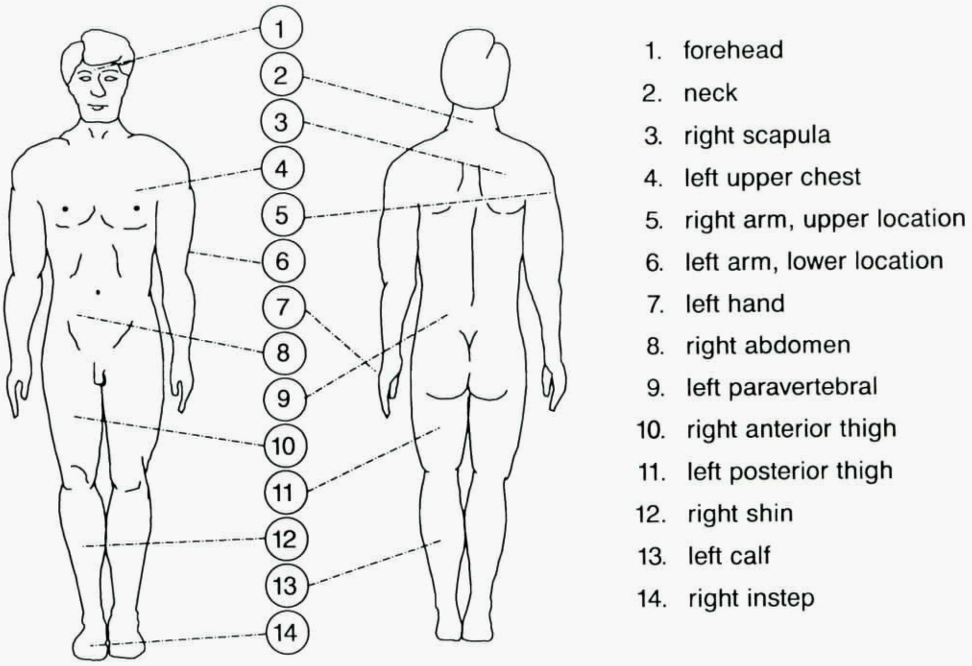

Figure 30. Sites for the measurement of skin temperature (ISO 9886).

Sensors. For the measurement of (a) body core temperature and (b) skin temperature, the following types of sensors can be used:

1) liquid expansion thermometers (a) (clinical use),
2) variable resistance thermometers (platinum resistor or thermistor) (a+b),
3) thermocouples (a+b),
4) infra-red (non-contact) thermometry (a: tympanic only + b: nude only).

The selection of the sensor should take the following into consideration: 1) shape (e.g. very small or flat with insulated outer side for skin temperature, to avoid influence of the environmental temperature), 2) hygiene, 3) safety aspects (electrical contact with the subject), 4) accuracy, and 5) time constant (<30 seconds).

Recording devices. Most sensors can be read using either a sensitive (40×10^{-6} volt°C^{-1}) Voltmeter (thermocouples) or a resistance meter (thermistors). Thermistors can also be read by a voltmeter after adding some electronics (linear thermistors). The sampling rate for recording of body temperatures can be as low as 1 minute^{-1}, as changes are relatively slow. Higher sampling rates can be used to reduce the effect of noise.

Regular calibration of sensors is needed, since their readings are easily influenced by effects of wire length, connector resistance, cross-influencing of thermocouples, etc. For body core temperature a resolution of .1°C and for skin temperature a resolution of .25°C is suggested as a minimal requirement (preferred: .05 and .1°C respectively).

Data analysis

Body temperature analysis does not require any special data analysis. Together, body core temperature and average skin temperature can be used to calculate average body temperature (Farnworth and Havenith, 1987):

In the heat, or in comfortable climates: $T_{body} = .8\ T_{core} + .2\ T_{skin}$

In cool or cold environments: $T_{body} = .6\ T_{core} + .4\ T_{skin}$

Besides the calculation of average skin or body temperature, as mentioned above, for some applications the calculation of body heat storage is required. This is usually calculated as heat storage change from neutral (i.e. 37°C T_{core} and 34°C T_{skin}), but can also be calculated from the start of an experiment (i.e. T_{core} start and T_{skin} start):

Body Heat Storage = T_{body}* 3.48 J g^{-1} (with 3.48 = specific heat of body tissue J g^{-1} C^{-1})

	instrument complexity	technical requirement	continuity of measurement	work	physical interference	health annoyance	cost	relevance hazard
body core:								
oesophageal	2	2	C	1-2	3	2	1	CW
rectal	0-1	0	C	0	2	1	1	CW
abdominal	2	1	C	0	2	2	3	CW
tympanic	2	2	C	1	3	2	1	W
auditory canal	1	1	C	1	3	1	1	W
oral	0-1	0	C	0	0	0	0	W
urine	1	0	D	0	2	0	0	W
skin:								
contact	1	1	C	1	1	0	2	CNW
no contact	2	1	D	0	0	0	3	CNW

Explanation:
instrument complexity: 0=simple, 1=some requirements, 2=complex
technical requirement for measurement procedure:
0=simple, 1= requires a competent person, 2=requires medical surveillance
continuity of measurement: C=continuous, D=discontinuous
work interference: 0=limited to time of measurement, 1=moderate interference, 2=strong interference with normal work process, depending on task
physical annoyance for person: 0=very slight and limited to duration of measurement, 1=limited, unless technique is not optimal, 2=of psychological nature without physical annoyance, 3=moderate physical annoyance
health hazards for the person: 0=no hazard, 1=potential hazard if technique not optimal, 2=potential hazard if anatomical abnormality of person
cost: 0=very low, 1=moderate, 2=medium to high, 3=high
relevance for evaluation of specific climate: C=cold, N=neutral (comfort), W=warm

Table 2. Different aspects of measuring methods/site for temperature of the human body.

Appendix I
SLEEP POLYGRAPHY

General background

Sleep polygraphy recordings can be helpful in the study of many operational problems. These recordings can be used to monitor any sleep period whether it is a long, overnight session or a brief nap during the day. For clinical and research purposes, sleep recordings are usually made in a sleep laboratory because of the available level of environmental control; however, as is the case with EEGs and other measures, recordings can be made in virtually any other environment.

Examinations of an individual's sleep cycle offers a crucial dimension of information about the impact of stressors encountered both before and during the sleep period. While most investigations are more interested in the direct effects of environmental and work-related stresses on performance during the duty period, the factors which interfere with restorative sleep should receive attention as well. If an operator is deprived of sufficient daily rest, his/her performance will ultimately become affected by cumulative fatigue.

The normal sleep cycle is affected by physiological, neurochemical, and cognitive events. Thus, it is reasonable to expect that operational stressors can impact sleep quality. By combining EEG data with eye movement and muscle data, the researcher can observe the typical human sleep pattern as well as the effects of any stressor which may disrupt this pattern.

Methods

The usual sleep cycle is characterized by a series of stages which can be characterized using sleep polygraphy techniques. First, there is attenuation of alpha activity (8-12 Hz) in the transition from wakefulness to sleep and this is followed by increased theta (2-7 Hz) and vertex sharp waves accompanied by slow eye movements and loss of facial muscle tone. Next, during stage 2 sleep, there are bursts of K-complexes (a special type of delta wave) and 12 to 14 Hz activity (sleep spindles) in the virtual absence of typical delta waves (.5-2 Hz). Next, there is progress into "slow-wave sleep" (stages 3 and 4) which is characterized by increasing amounts of delta activity. During the night, there are shifts between the slow-wave stages and REM (rapid eye movement) periods which consist of desynchronized, low-amplitude EEG with no K-complexes or spindles, the virtual absence of muscle activity, and the occurrence of sporadic, rapid eye movements. As the night progresses, the REM periods typically become more numerous whereas the amount of very deep (slow wave) sleep decreases.

The method used to collect and analyze sleep involves a combination of measures discussed earlier. The measures are EEG, EOG, and EMG.

Electrodes/recording devices. The electrodes used to collect EEG, EOG, and EMG data for sleep studies are identical to those described earlier for the collection of EEG and evoked responses (see Appendix B). The EEG electrodes are typically placed according to the 10-20 system, and the minimum channel configuration is discussed below. Collodion is typically used to attach the EEG electrodes because they must be kept in place over night and the electrolyte cannot be allowed to dry out. In the context of a sleep laboratory, sleep is recorded by a polygraph, a set of amplifiers, and sometimes an additional recording system. Newer developments are highly computerized and use CRT displays as opposed to standard pen and ink records. If sleep data is to be collected outside of the laboratory, portable recorders can be used. They are commercially available and have 4 or 8 channels for recording physiological signals on cassette tape. Once the data are taped, they can be reviewed on a computerized display or written out on a standard polygraph trace.

Sleep recording. Sleep polygraphy combines EEG, EOG, and EMG measurements. If only 4 channels are available, one EEG, two EOG, and 1 EMG channel are used.

For the EEG, the C4-A1 or C3-A2 derivation is recommended. In order to aid in determining awake and stage 1 sleep, the O1-A2 or O2-A1 derivation can be used to enhance the recording of alpha activity if additional recording channels are available. Electrode impedances should not exceed 5 KOhms at the beginning of the recording. A typical filter setting is a time constant of 0.3 s and a low pass filter at 30 Hz. If paper is used for the recording, a paper speed of 10 mm/s and a pen deflection of 50 microvolts/10 mm are used.

To avoid confusion between the eye movements seen in rapid eye movement (REM) sleep and other similar signals, two EOG channels are needed. The recommended procedure is to record: 1) the potential between an electrode approximately 1 cm above and slightly lateral to the outer canthus of one eye and a reference electrode on either an ear lobe or mastoid, and 2) the potential from an electrode 1 cm below and slightly lateral to the outer canthus of the other eye to the same reference. In these recordings, rapid eye movements are typically out of phase whereas artifacts are usually in phase. DC channels are typically used for these recordings, however AC channels can be used. The time constant should be set at .3 and the low pass filter at 10 Hz. Sensitivity is generally 50 microvolts/ 7.5 mm.

EMG activity is used for the identification of REM periods when it is lowest. The filter settings for EMG are a time constant of 0.1 s and a low pass at 70-120 Hz. The sensitivity should be 20 microvolts/10 mm or higher, depending on the subject.

Data analysis

Sleep recordings are scored for every 30 s epoch according to the rules of Rechtschaffen and Kales (1968). The scoring yields a sequence of sleep stages 1 to 4, REM sleep, movement time, and waking times. This analysis is sometimes complemented by analyzing the time course of spectral power produced by slow wave sleep if one has access to a computerized scoring system. Analyses generally include time to sleep onset, amount of time spent awake after sleep onset, amount of time spent in each stage of sleep, and latency to the first REM period.

AGARD-AR-324

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AGARD ADVISORY REPORT 324 - APPENDIX J

Register of Psychophysiologists (on microfiches)

Liste de Psychophysiologues
(sur microfiches)

by

Glenn A. Wilson and **Laura L. Mulford**

North Atlantic Treaty Organization
Organisation du Traité de l'Atlantique Nord

Preface

The NATO Advisory Group for Aerospace Research and Development (AGARD) was created to promote communication and collaboration on aerospace related topics. One of the functions of AGARD is to sponsor Working Groups which address a specific aerospace problem. Working Group 19 of the Aerospace Medical Panel (AMP) on "Psychophysiological Assessment Methods" was formed in 1992 to investigate psychophysiological methods of assessing human performance. Its major function was to develop an AGARD Advisory Report which provided background information on the uses of these methods in aerospace research and application environments.

Advisory Report 324, "Psychophysiological Assessment Methods" presents a comprehensive overview of available psychophysiological techniques. The Report reviews the types of aerospace problems that have been addressed with these methods, discusses how these techniques have been applied in areas relevant to aerospace environments, gives examples of how these measures have been used, and provides detailed information on the actual implementation of these measures. Practical issues such as pilot acceptance and research strategies are also discussed as are guidelines for the collection of each type of physiological data. An extensive bibliography is also included. The Advisory Report is not meant to be a comprehensive handbook on psychophysiology but rather focuses on the unique aspects of applying these methods to the operational setting.

Since the use of psychophysiological methods requires training and experience, this Register of Psychophysiologists was developed for the novice user in order to provide a source of expertise. Experienced users of these techniques can also benefit from using this Register by being able to identify users of specific techniques and those who work in applied areas.

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Préface

Le Groupe Consultatif pour la Recherche et les Réalisations aérospatiales de l'OTAN (AGARD) a été créé afin de promouvoir la communication et la collaboration dans le domaine aérospatial. L'une des fonctions de l'AGARD est d'organiser des groupes de travail pour examiner différents problèmes spécifiques à ce domaine.

Le Groupe de Travail No. 19 du Panel de Médecine Aérospatiale (AMP) sur "Les Méthodes d'évaluation Psychophysiologiques" a été formé en 1992 pour examiner les méthodes psychophysiologiques d'évaluation des performances humaines. Le groupe a eu pour fonction principale d'établir un rapport consultatif AGARD donnant des informations de base sur l'emploi de ces méthodes dans les milieux de recherche et d'applications aérospatiales.

Le rapport consultatif No. 324 "Les Méthodes d'évaluation Psychophysiologiques" fait un tour d'horizon complet des techniques psychophysiologiques actuelles. Le rapport examine les problèmes qui ont été abordés à l'aide de ces méthodes dans le domaine aérospatial, discute la façon dont ces techniques ont été appliquées dans des domaines qui touchent l'environnement aérospatial, donne des exemples de l'emploi des mesures et fournit des informations détaillées pour une mise en oeuvre concrète. Des questions d'ordre pratique telles que l'acceptation par les pilotes et les stratégies de recherche sont également examinées, tout comme des propositions de directives pour la collecte de chaque type de donnée physiologique. Le rapport contient une bibliographie étoffée. Ce rapport ne prétend pas être un manuel complet sur la psychophysiologie; il traite plutôt les aspects spécifiques de l'application des méthodes aux cas opérationnels.

Puisque l'emploi de méthodes psychophysiologiques demande une certaine formation et une certaine expérience, cette liste des psychophysiologues a été développée comme source d'expertise pour l'utilisateur novice. Toutefois, l'utilisateur chevronné pourra également en profiter, car ce document lui permettre d'identifier des utilisateurs de techniques spécifiques, ainsi que ceux qui travaillent dans des domaines d'applications.

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Special recognition should be given to Dr Glenn Wilson for the design of the registry database and Ms Mulford for data entry, collating and preparation of the information contained in the Register.

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14. Abstract

The study of human-centered operationally-relevant problems in aerospace and aviation research and development can be enhanced by the inclusion of psychophysiological techniques. By measuring physiological variables in conjunction with performance and subjective measures, a more thorough understanding about the processes underlying performance can be obtained. This report presents a summary of the general utility of psychophysiological assessments, the types of applied problems which can be addressed with these assessments, and the qualities of several psychophysiological techniques. In addition, safety and ethical considerations, guidelines for making determinations about the most appropriate research strategy, and three research examples are discussed. The report concludes with a series of appendixes which offer the reader information on how to collect and analyze each of the psychophysiological measures.

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