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Cognitive and Vigilance Performance
- (2) **Type of report:** Summary of Research
- (3) **Name of principal investigator:** David F. Dinges, Ph.D.
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- (5) **Name and address of the recipient's institution:** Institute for Experimental Psychiatry Research Foundation
290 Sycamore Avenue
Merion Station, PA 19066
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This project had three broad goals: (1) to identify environmental and organismic risks to performance of long-haul cockpit crews; (2) to assess how cognitive and psychomotor vigilance performance, and subjective measures of alertness, were affected by work-rest schedules typical of long-haul cockpit crews; and (3) to determine the alertness-promoting effectiveness of behavioral and technological countermeasures to fatigue on the flight deck. During the course of the research, a number of studies were completed in cooperation with the *NASA Ames Fatigue Countermeasures Program*. The publications emerging from this project are listed in a bibliography in the appendix. Progress toward these goals will be summarized below according to the period in which it was accomplished.

1989-1992: During the initial years of this project, we participated in the design, implementation, data acquisition, and data analyses of the NASA Cockpit Rest Study. The Cockpit Rest Study was the first to systematically involve an experimental test of a sleep-based fatigue countermeasure (i.e., a 30-minute planned nap in the cockpit seat) in an actual long-haul flight environment. It involved physiological and performance monitoring of 21 long-haul commercial cockpit crewmembers during four trans-Pacific flight legs. The results from this study demonstrated that objective laboratory based, portable tests of performance that we developed (i.e., the psychomotor vigilance task or PVT), could be used to document fatigue during flight and its relief by a nap countermeasure. The entire Cockpit Rest study and results were written up, and formed the basis for the FAA to evaluate cockpit rest and issue an advisory circular on it. Other aspects of the data from the Cockpit Rest Study have also been published.

1992-1993: In parallel with related work described above and below, we assisted the NASA-Ames Fatigue Countermeasures Program in planning and initiating a study of the effects of shift work (especially night work) on alertness, performance, and circadian adjustment of NASA Johnson Space Center ground controllers during space shuttle missions. A study was conducted in which we generated forms and booklets for, and analyzed, over 24,000 pages of self-reported alertness and cognitive performance data from JSC personnel during an STS mission between December and January of 1992-3. The findings were integrated with those of the NASA Ames Fatigue Countermeasures Program and a briefing was provided to Johnson Space Center personnel.

We also completed implementation into NASA Ames Fatigue Countermeasures Program protocols of three short-duration neurobehavioral probes: (1) the portable psychomotor vigilance (PVT-192) test for assessing sustained attention in flight crews; (2) the probed-recall memory (PRM) test for assessing working memory; and (3) subjective performance and effort ratings designed to improve evaluation of subjective impressions of fatigue.

1993-1994: We participated in completion of phase I of NASA Ames' studies of pilots' sleep in aircraft bunks during flights, which involved completion of a survey by more than 8,000 long-haul cockpit crew members. We participated in the development of the survey instrument to assess the perception of sleep by long-haul flight crews in two environments: while at home and in onboard crew rest facilities during long-haul flight operations. This study was successfully completed in 1994. We participated in evaluation of the results, specific analyses of the data, and interpretation of the findings.

In 1993, we also performed data reduction and analyses on physiological and performance variables from the P.I.'s NIH-sponsored laboratory study of the effects of 64 hr of sleep loss on healthy adults. In this study the NASA Ames Fatigue Countermeasures Program participated by acquiring the ambulatory EEG-EOG data in order to identify the physiological correlates of fatigue. For comparison purposes, the PVT performance results from this study, as well as the wrist actigraphy and related subjective results from the study were combined in a database and compared to the results on these measures from the NASA Ames Cockpit Rest Study. During 1994, data from three newly completed protocols were added to the database. Analyses were conducted to identify the range of individual differences in PVT performance lapsing during a night without sleep. This collaborative database served as a key resource in the validation of specific physiological and behavioral dependent variables to be used in future NASA fatigue countermeasure studies.

In addition, we also assisted the NASA Ames Fatigue Countermeasures Program in completion of a study to determine whether miniaturized psychomotor vigilance performance devices and rest-activity monitors could be employed in aviation field protocols in which no observer was present. A total of 15 long-haul flight crew members were followed for a period of 7 days, which involved two augmented flights of approximately 11 hours duration.

1994-1995: We collaborated with NASA Ames Fatigue Countermeasures Program in a major survey entitled Studies of Regional, Commuter, and Corporate Flight Operations. Data acquisition on the regional project was completed in 1995. We participated in development of the survey instruments used in these studies. More than 2,000 pilots and officials from regional, commuter, and corporate aviation sectors completed the surveys.

In this period, we also completed a study of the reliability of individual differences in performance-impairing reactions to night operations and sleep loss. This focused on data analyses of PVT performance data acquired from various laboratory and field studies of fatigue conducted by our laboratory and the NASA Ames Fatigue Countermeasures Program. During 1995, preliminary analyses revealed that approximately 10-20% of healthy subjects (depending on the cutoff criterion) had a severe PVT performance decrement on night flights. Subsequent analyses revealed that this decrement was a more-or-less stable characteristic of subjects, suggesting that some flight crew members are consistently prone to severe vigilance performance impairment during normal nocturnal operations.

We also completed a laboratory study of the Effects of Sleep Restriction on Performance. Cumulative sleep loss has consistently been found in NASA studies of transmeridian flight crews. In an effort to determine the nature of the mathematical growth of performance deficits accruing from cumulative sleep loss, during 1995, we completed a laboratory study (NIH funded) of daytime performance in 16 healthy subjects restricted to 5 hours sleep a night for 7 consecutive nights. These results were compared to those observed from NASA's field studies of long-haul pilots. These findings were not entirely predicted by current biomathematical models of alertness, and suggest that the cumulative deficits in performance from sustained sleep restriction of the kind experienced by some flight crew members may escalate to serious levels.

We participated in the design and measurement implementation of the Augmented Long-Haul Field Study, which focused on the physiological sleep of cockpit crews in crew rest facilities during actual flight operations. We provided the equipment, protocols, and some manpower for collection of data on flight crews' PVT performance and cognitive performances, subjective activation, and wrist activity monitoring. The NASA Ames Fatigue Countermeasures Program initiated this study in 1995, and significant progress was made on data acquisition. Extensive probed performance data (i.e., PVT and PRM tasks) were gathered (along with physiological and environmental data) on a total of 39 cockpit crew members: 17 flight crew members in 747-400 aircraft; 8 flight crew members in 747-200 aircraft; 11 flight crew members in 767 aircraft; and 3 flight crew members in long-haul corporate aircraft.

1995-1996: Data analyses of performance parameters and subjective alertness measures from the Augmented Long-Haul Study were completed in 1996 on 39 cockpit crew members. Data were evaluated for the effects of sleep in the crew rest facilities, flight leg, time of day, and aircraft type/operation. The findings were integrated with physiological, behavioral, and environmental variables analyzed at NASA. Performance variables were compared to equivalent measures from the NASA Cockpit Rest Study, and from the P.I.'s various laboratory experiments on the effects on performance capability of night work, as well as partial and total sleep deprivation. These comparisons provide a calibration of the level of neurobehavioral functioning across NASA studies.

During this period we also collaborated with the NASA Ames Fatigue Countermeasures Program in an examination of the scientific basis for federal regulations governing work-rest schedules of flight crews. The document was used by the FAA as one of a number of key sources of information in its Notice for Proposed Rule Making to amend existing regulations to establish one set of duty period limitations, flight time limitations, and rest requirements for flight crew members engaged in air transportation.

1996-1998: In 1997, the P.I. participated in a roundtable discussion and meeting sponsored by the Transportation Research Board of the National Academy of Sciences regarding the scientific basis for proscriptive work-rest scheduling in transportation modes. This work was completed in 1998 with the publication of a review of fatigue countermeasures relative to flight and duty time considerations.

As a prelude to a NASA Ames Fatigue Countermeasures Program study of activity breaks as fatigue countermeasures during long-haul night flights, our laboratory performed a study demonstrating that even mild forms of activity (e.g., postural changes) and mild stimulation (e.g., social and cognitive) could markedly enhance alertness and prevent performance lapses, especially at the low point in the body's endogenous circadian rhythm during night operations. The results of our study

helped the Fatigue Countermeasures Program to design and implement a study in the NASA Ames 747-400 cockpit simulator to measure the effects of brief activity breaks on the performance and alertness in 28 flight crew members during night flights. We provided conceptual, statistical, and logistic input to the study design and implementation, as well as equipment, manpower, and protocols for collection of data on flight crews' psychomotor vigilance and cognitive performances, and subjective activation. A total of 28 pilots were studied during a simulated night flight. The results of this study are currently being prepared for publication.

The 747-400 simulator study on the effects of activity breaks also served as the first systematic effort to objectively record pilot alertness levels during flights using video of the face and eyes. In laboratory research we performed during this period for the U.S. Department of Transportation and Air Force Office of Scientific Research, we tested the extent to which 6 new on-line, miniaturized fatigue detection technologies could reliably track alert and fatigued psychomotor vigilance performance. This included two EEG algorithms, two eye-blink monitors, one head position sensor array, and one video-based system for tracking slow eyelid closures. Only the latter technology proved reliable in all subjects at all times. This technology was deployed in the NASA Ames Fatigue Countermeasures Program study of activity breaks as fatigue countermeasures during long-haul night flights. The results provided the first data on on-line continuous monitoring of flight crew alertness. Boeing Commercial Airplane Group has shown very high interest in pursuing these discoveries to develop an on-board, objective crew alertness management system.

In summary, we believe that the outline of our accomplishments in this project amply illustrate that we have achieved our goal of helping to provide the NASA Ames Fatigue Countermeasures Program with novel, scientifically valid behavioral, biological, and technological strategies and techniques for enhancing physiological alertness, performance, and safety in flight crews. In addition to actively performing research for and with the NASA Ames Fatigue Countermeasures Program during the past 9 years, our laboratory has also provided the program with the detailed results of studies we have completed for other federal agencies (e.g., NIH, DOD, DOT) on the effects of novel fatigue countermeasures that have been validated to work in controlled laboratory experiments we have performed (e.g., our development of "prophylactic napping" led to NASA's demonstration of "planned cockpit rest" as an effective fatigue countermeasure). We have also been able to inform the Program of interventions that have not proven to be effective in controlled experiments, and therefore saved the Program the expense of carrying out such studies. Finally, during the latter years of this project we have been involved in fatigue countermeasure work for long-duration human space flight and the manned mission to Mars. This work directly connects to many of the issues being addressed with the Fatigue Countermeasures Program at Ames. Dr. Dinges is a funded investigator and Associate Team Director on the Human Performance Factors, Sleep, and Chronobiology Team of the National Space Biomedical Research Institute, supported by NASA. He also serves on the Scientific Working Group for the Human Research Facility for the International Space Station, and together with Dr. Neri at NASA-Ames Research Center, he is part of a new working group on fatigue and performance monitoring in astronauts.

Negative Inventions Statement: No inventions came out of this research.

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None.