THE USE OF MULTIPLE PHYSIOLOGICAL MEASURES
TO DETERMINE FLIGHT SEGMENT IN F4 PILOTS

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ABSTRACT

Discriminant analysis techniques were used to classify flight segments for ten F4 pilots from data recorded during air-to-ground training missions. Cardiac and eye blink parameters were used as variables and 93% correct classification was found. Application of this technique to flight environments of the future are discussed.

INTRODUCTION

The rapid, accurate and continuous monitoring of pilot state and/or workload is desirable in modern aircraft systems. The cognitive and physical aspects of flying modern aircraft can place exceptionally high demands on the modern aviator. In the design, test and evaluation of new generations of aircraft and the up-grading of current systems, accurate and objective measures of operator workload are needed. Physiological measures have been used in a number of studies to determine flight crew workload and state during flight. Heart rate, respiration, brain waves and eye blinks have been used, with heart rate having the largest application (Roscoe, 1987, Sterman, et al, 1987 and Wilson, et al, 1987). Both civil and military flights have provided the scenarios in which physiological data have been recorded. There are primarily two approaches that can be taken when using physiological data during flight; evaluation or monitoring. Physiological data have historically been used to evaluate the effects of flight, simulation or cockpit design upon aircrew physiology. The newer approach is to monitor pilot state and/or workload with the physiological data and use this information to signal over or under load conditions to alert the pilot and/or system.

When evaluating the effects of flight upon the pilots' physiology, data from an entire flight, from selected flight segments or from simulator missions have typically been analyzed to determine the consequence of the various mission events upon the physiological variables. For example, increased heart rate has been observed at take-off, landing and during other high workload portions of flight. Since each of the physiological measures may index a different aspect of operator state and information processing, each one is typically analyzed and interpreted separately. With this approach, group data are typically analyzed, losing the individual pilots' responses. The value of this approach is to show the average response pattern for the whole group and to permit testing for statistically significant effects due to mission workload or cockpit design. This is very useful to identify overall trends, but obscures individual pilot response patterns.

The second, monitoring, approach is to use the physiological data to determine the state of the pilot and/or the level of workload during the mission. This approach uses the physiological data as predictors of pilot state and/or workload level and can be used with each pilots' physiological variables individually or in combination. As mentioned above, the nature of the changes to expect in the individual physiological variables as a function of mission event is generally known. It is our feeling that combining these measures should provide the best prediction of pilot state and/or workload since flight is a multidimensional task utilizing many aspects of the human operators' capabilities and functions. For example, it has been our experience that heart rate increases at both take-off and approach to landing but on the basis of only the heart rate it is difficult to identify whether the pilot is taking off or landing. Eye blink rate on the other hand, typically is lower during the approach to landing and other visually demanding segments. By combining these two variables it is possible to determine which of several segments the pilot is engaged in at a particular time. That is, heart rate increase with an associated decrease in blink rate indicates that the pilot is in the approach to landing phase.

The purpose of this paper is to report our efforts to formally assess the merits of combining physiological data by applying discriminant analysis techniques to predict mission segment. Discriminant analysis is a statistical procedure that provides a linear combination of observations to make classifications. Further, we used this statistical technique as a method of combining these several types of physiological data to determine the utility of combining measures and to compare the combination with the individual measure estimates.

METHODS

Ten F4 crews were instrumented to record electrocardiograms (ECG), respiration, electrooculograms (EOG) and electroencephalograms (EEG) during air-to-ground training missions. Portable recorders which recorded seven channels of physiological data (Del Mar Neurocorder) were used. After each flight, 8 two-minute epochs were identified from mission segments of interest and the associated physiological data were digitized and analyzed on a Neuropsychological Workload Test Battery (Wilson and O'Donnell, 1987). For the present purposes only ECG and EOG data will be reported. The flight segments used were: Pre-take-off (prior to aircraft roll), Take-off, Low-level flight, Early range segment, Late range segment, Cruise back to base, Approach to landing and Touch-down.

The physiological variables used were mean cardiac inter-beat-interval (IBI), standard deviation of the IBIs (IBISD), mean blink rate (BR), mean blink interval (IBLI), standard deviation of the blink intervals (BISD) and mean blink duration (BD).

Linear multivariate discriminant analysis procedures (BMDP 7M) were used to make predictions of flight segment from the physiological data with all variables combined and with some of the measures considered individually. The jackknife procedure was also used, it provides an estimate of classification accuracy by leaving each case out, in turn, and calculating the classification of all other variables. The jackknife procedure provides an estimate of the ability to classify the data set. The data for each pilot were analyzed separately because of the known, wide individual differences in response patterns of physiological data.

RESULTS

The results of the discriminant analysis for the flight data are represented in Table I. For each pilot the variables that the program used to classify the mission segments are listed, as well as the percent of correctly classified segments for both the empirical classification and the classification resulting from the jackknife procedure. Note the wide variety and mix of variables used for classification for each of the ten pilots.

TABLE I
Variables Used to Classify Segments
and Percentage Correct Identification.

Pilot	Variables Used	Percentage Correct	
		Empirical	Jackknife
1	IBLI	80	80
2	BR IBI	100	60
3	IBI IBISD	100	90
4	BR BISD	100	60
5	BD IBI	100	70
6	BR IBI	100	60
7	BR IBI	100	80
8	IBI IBLI	80	60
9	IBI IBISD	100	70
10	BR	60	60

For seven of the ten pilots, 100% of the eight segments were correctly classified. The variables most frequently isolated were IBI (7 times), BR (5 times), with the others isolated as follows: IBLI (2 times), IBISD (2 times), BD (1 time) and BISD (1 time). Two variables occurred together three times, they were IBI and BR.

Since IBI and BR appeared most consistently, further analyses were performed with just these two variables alone and in combination. The results are listed in Table II.

TABLE II
Percent correct identification of mission segments
for IBI, BR and combined IBI and BR.

Pilot	IBI	BR	IBI and BR
1	90	60	80
2	90	70	100
3	80	60	80
4	80	70	100
5	80	90	100
6	80	80	100
7	100	70	100
8	80	80	90
9	90	70	100
10	70	70	80

There was an improvement in the percentage of correct classifications of mission segments when the two variables were combined. The mean percent correct for the ten pilots was 84% for IBI alone, 72% for BR alone and 93% for the combination of IBI and BR. We cannot determine whether this improvement was statistically significant since there does not appear to be any reliable statistical technique for comparing the classification accuracy of multi-class discriminators. However, it is noteworthy that there was a 9% and a 21% improvement for the combination over IBI and BR, respectively.

DISCUSSION

Discriminant analysis with physiological data has relevance for classifying mission segments during flight. Using this procedure, we were able to correctly classify 93% of the segments for 10 pilots. This is a quite good result, especially since the combined measures correctly classified all of the segments for 6 of the 10 pilots with the lowest percentage of correct classification being 80%. This indicates that this method should be considered for use in situations where pilot state and workload must be known. Since the physiological data are continuously available it should be possible to have continuous, on-line information about pilot state and workload.

available at all times. A computer dedicated to monitoring and determining pilot state could compare its assessment with data derived from the aircraft control and navigation computers. Detecting discrepancies between the pilots' actual physiological state and what might be expected at a particular time, the computers could alert the pilot and/or the system to take corrective action. The advantage to this system is that non-emergency alarms (or other methods of getting a pilots' attention) would be set only under certain conditions of pilot workload and therefore would not lose their novelty.

On the basis of the variables selected by the discriminant procedures listed above, it is clear that no standard set of variables can be used for all pilots. The physiological data from each pilot must be used to determine the appropriate variables for classification. This is shown by the mix of different variables used by the discriminant program to classify the mission segments across the ten pilots. Further, combining the variables provides better segment identification than using them independently. By comparing Table I with Table II, it can be seen that the classification accuracy for Pilot 3 is better if IBISD is included in the variables used in the classification. Including data from other physiological systems could provide even better predictors, since a wider range of physiological systems would be used to determine mission segment. We plan to add respiration, additional measures of heart rate variability, and EEG to the database.

The application of the discriminant procedures to actual flight or other "real world" situations is not as difficult as it may appear. The discriminant analysis is accomplished off-line, using a mainframe or PC computer. However, only the classifiers need to be present for the classification of the physiological data during flight. The physiological data could be collected with miniature amplifiers worn by the pilots and the data reduction and classification could be done by the small on-board computer. The procedure would be to collect physiological data during a mission of interest, the discriminant analysis would be performed upon this data off-line to derive the classifiers. The classifiers would then be given to the on-board computer for determination of segment during flight. Depending upon the aircraft resources, it would be possible to include flight information from the aircraft in the algorithm used by the on-board computer to improve the accuracy of the classifications.

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