

PSYCHOPHYSIOLOGICAL MEASURES OF COGNITIVE WORKLOAD IN LABORATORY AND FLIGHT

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ABSTRACT

Psychophysiological data have been recorded during different levels of cognitive workload in laboratory and flight settings. Cardiac, eye blink and brain data have shown meaningful changes as a function of the levels of mental workload. Increased cognitive workload is generally associated with increased heart rates, decreased blink rates and eye closures and decreased evoked potential amplitudes. However, comparisons of laboratory and flight data show that direct transference of laboratory findings to the flight environment is not possible in many cases. While the laboratory data are valuable, a data base from flight is required so that "real world" data can be properly interpreted.

INTRODUCTION

Psychophysiological measures can provide continuous estimates of operator workload in a non-invasive manner. They are relatively easy to obtain and are useful in many situations. In order to fully understand these measures and their relationship to human performance, laboratory experiments are conducted that provide a great deal of control over the subject's environment so that extraneous variables can be eliminated or controlled. This permits us to develop databases and to develop and test theories so that we can understand the basic phenomena. This gives us a framework within which we can collect physiological data in flight and properly interpret it, assuming that there is a direct relationship between laboratory and flight data. This may not be the case, since they are quite different environments. For the past several years we have performed laboratory experiments exploring the realm of cognitive workload so that we would be able to properly use physiological data in the flight environment. By understanding the basic relationships between cognitive workload and physiological responses, we are better equipped to deal with flight data. As reported below, we have had mixed success applying what we have learned in the laboratory to flight. This report will deal with three of the physiological variables that we have extensively investigated in the laboratory and applied to flight. They are cardiac activity, eye blinks and brain activity.

CARDIAC ACTIVITY

Heart rate has a long history of use in psychophysiological research and has been the most widely used physiological measure in flight studies. Since the heart's main function is to provide nutrients and hormones to body tissues and remove metabolic by-products, its activity is controlled by the physical demands of the body. However, cognitive activity, performed by the cerebral cortex, also places demands upon the cardiac system and causes changes in its activity as well. With regard to the cognitive effects, the typical finding is that heart rate increases with increasing cognitive workload. This includes comparing no-task to performing a cognitive task (Molen, Somsen &

Orlebeke, 1985), assessing the effects of increasing task difficulty in single task (McCanne & Hathaway, 1979) and multiple task situations (See Wilson & Eggemeier for a review, 1991).

In our laboratory we have studied the effects of graded changes in cognitive activity produced by changing task difficulty in a standardized task battery. We were unable to reliably find the expected increases in heart rate with increased task loads (McCloskey, 1987; Wilson et al., 1986; Yolton, et, al., 1987). After careful comparison with the literature, it became obvious that there were two important methodological differences between our studies and those in the literature. Both of these have very direct bearing upon the issue of making use of physiological measures in "real world" situations such as flying. The first was that we practiced our subjects to a performance criterion before we collected the physiological data. The second was that our subjects were all accustomed to the laboratory since they served as subjects in many experiments in different laboratories. The studies in the literature typically did not practice their subjects or gave them minimal familiarization with the tasks to be performed and their subjects were naive to the laboratory and laboratory practices. In effect, these subjects were learning the tasks and becoming accustomed to the laboratory as the data were being collected. We performed a study using naive subjects and measured their heart rates while they performed 30 blocks of trials of a mathematics task having two levels of difficulty that was new to them. We found significant increases in heart rate to the difficult level of the task only during the first four blocks of trials and not in the remaining blocks (See Figure 1). Further, there was a significant decrease in heart rate from beginning to end of the three-hour session. These data demonstrate that learning and adaptation to the data collection environment are extremely powerful. This is a crucial variable when collecting data from subjects such as pilots and air crew who are highly over practiced in their jobs and extremely familiar with their work environment. We must beware of interpolating from the standard laboratory data to "real world" environments: the laboratory data may not be at all appropriate to extrapolate to the "real world".

The range of the data and the dynamics of the cardiac system also are different in laboratory and flight environments. We found four to ten percent increases in heart rate for F4 pilots and weapon systems officers (WSOs) when performing a laboratory tracking task compared to a resting baseline. During flight, the pilots' heart rates increased up to 45% and the WSOs up to 35% when engaged in air-to-ground training missions (Wilson & Fullenkamp, 1991). This large discrepancy in percent change suggests that the cardiac system dynamics may well be quite different in these two situations and follow different functions.

The variation of the heart rhythm has been reported to be influenced by cognitive activity (Mulder & Mulder, 1980). Mental activity decreases the variation of the cardiac rhythm, making it more constant from beat to beat. These results are derived from laboratory studies and we tested the utility of heart rate variability (HRV) in flight by examining the HRV in several segments of the F4 study mentioned above (Wilson, 1991). These data included the laboratory tracking task segments and several flight segments including take-off, cruise, bombing range and landing (See Figure 2). We found that the HRV, calculated three ways, provided only either-or information. That is, situations requiring higher levels of mental workload were all associated with the same level of HRV reduction including the laboratory tracking task. The HRV measure was not sensitive to different levels of workload, it was at either one level or the other for all segments, laboratory and flight. Simple heart rate, on the other hand, demonstrated a great deal of sensitivity to

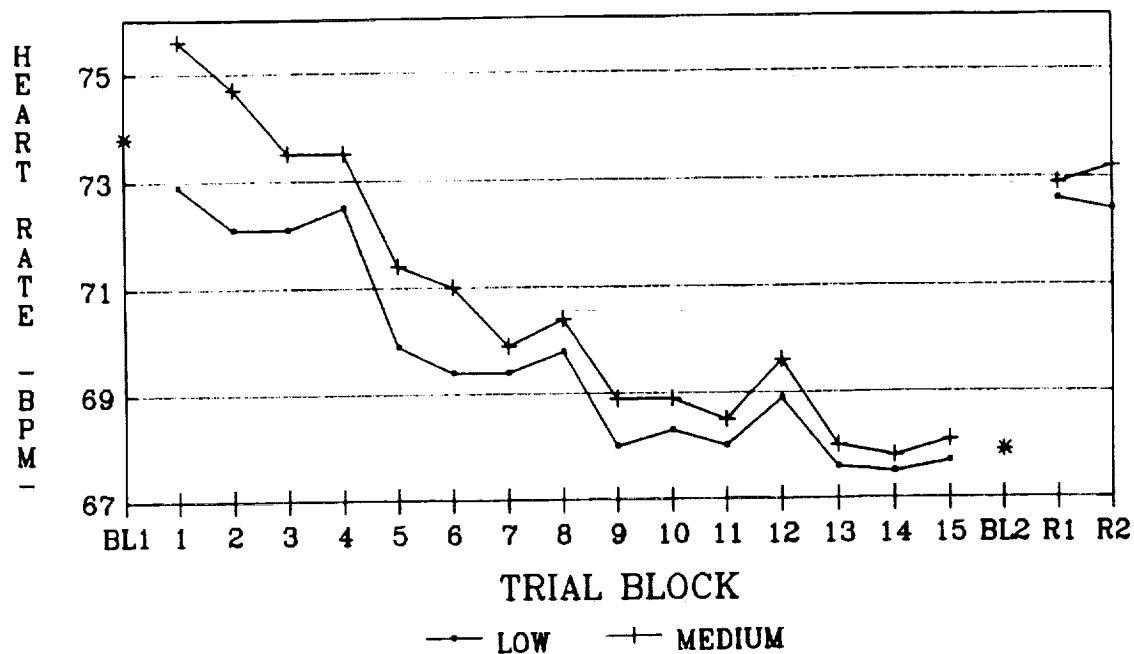


Figure 1. Mean heart rate for eight subjects while performing 15 three-minute blocks of a mathematics task at two levels of difficulty. Pre- and post-task baselines were included.

the several levels of cognitive demand, with the flight segments associated with higher heart rate levels than the laboratory tracking task (See Figure 3). From these data, HRV is not a sensitive measure of mental workload during flight.

EYE BLINK ACTIVITY

The eyes have been called the windows into the soul - this may or may not be true, but the eyes do regulate and process visual input. Blink activity interrupts the flow of visual information so visually demanding situations should decrease blinking and shorten the duration of the blinks (Stern, Walrath & Goldstein, 1984). Preliminary data from a recent sleep loss study in our laboratory showed that blink rate was lowest of the twelve tasks during the tracking task and that blink rate actually increased after the one night of sleep loss.

Blink rates were measured in the F4 study mentioned above and were found to be very low during the laboratory tracking task. In fact, one subject blinked only one time during the two-minute task. However, when compared to the flight data, the laboratory blinks were seen as actually being inhibited. The lowest blink rates during the flight were recorded during the bombing range segments and the rate was approximately three times higher than that found when performing the laboratory tracking task. The laboratory task produced abnormally low blink rates when compared to a very highly visually demanding "real world" task.

In a study with A7 pilots in which they flew three times, once as lead of a four ship formation, once in a wing position and once in a simulator, the shortest blink closures were when they flew in the wing position (Wilson, Skelly, Purvis, Fullenkamp & Davis, 1987). This was no doubt due to the higher visual demands associated with maintaining ship position relative to the lead while the lead position does not demand as much concern about relative position.

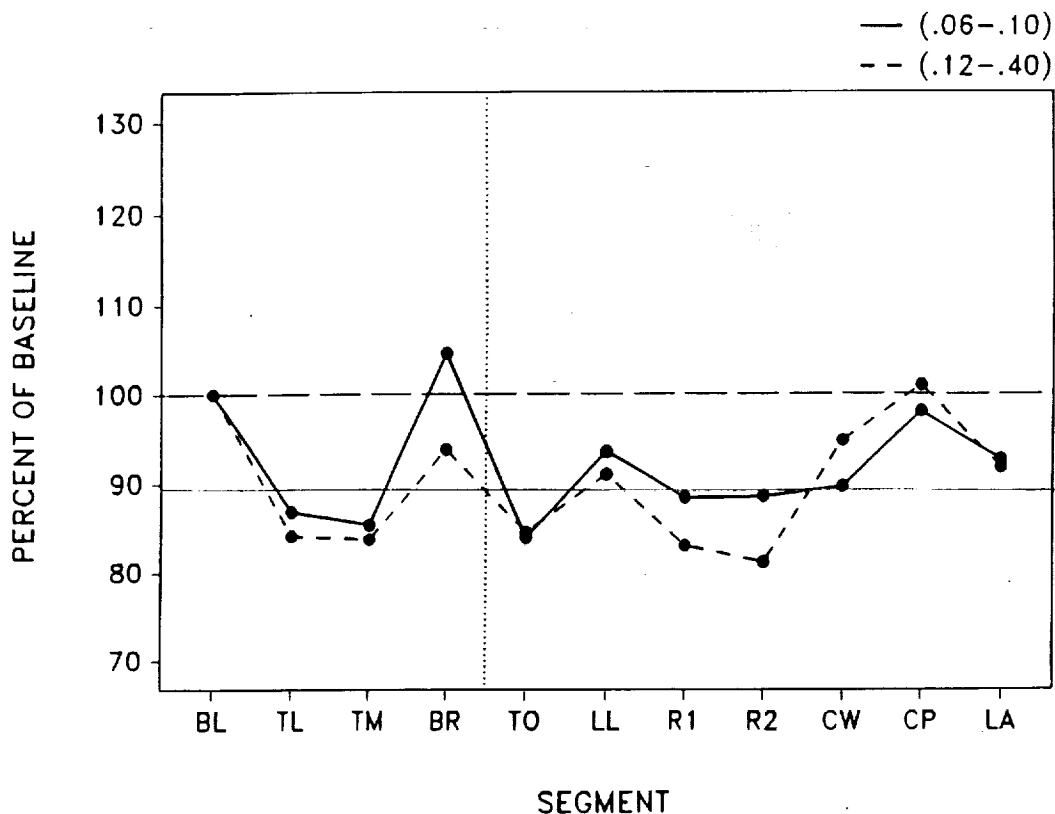


Figure 2. Heart rate variability for the 0.06 to 0.10 Hz and the 0.12 to 0.40 Hz bands from 10 F4 pilots during 11 segments. The solid horizontal line separates the statistically significant values. Note that there are only two groups, which include both flight and ground segments. The segments are listed on the X-axis and are: BL - baseline, TL - low difficulty tracking task, TM - medium difficulty tracking task, BR - preflight briefing, TO - take-off, LL - low level flight, R1 and R2 - bombing range segments, CW - Cruise - WSO flying, CP - cruise - pilot flying, LA - landing.

Further, in a recent study with students at the Air Force Test Pilot School, we found that blink pattern was determined by the nature of the task. The students participated in familiarization flights with radar and infrared detectors. Their job was to detect the radar reflector and identify the individual components of the reflector. Blinks were suppressed during the search and identification phases and occurred after identification or when adjusting equipment. This demonstrates that blink activity can be controlled by the visual demands of the job and long periods of blink inhibition can naturally occur if the operator is engaged in a single task that is visually demanding, such as operating a radar set.

A final example is that of a C-130 transport pilot performing a low altitude parachute extraction (LAPES). During the maneuver, the aircraft is flown very close to the ground and five to fifteen tons of equipment are pulled out of the back of the aircraft with parachutes. This, of course, causes the flight characteristics of the aircraft to change dramatically and very rapidly. This is a potentially dangerous maneuver and is associated with high cognitive workload. Our data, seen in Figure 4, showed that the LAPES was preceded by a slow, regular pattern of blinking with moderate closure durations and the actual LAPES segment itself produced inhibition of blinking for approximately 10 seconds and increased heart rate. Following the LAPES the eye blinks became more normal in pattern and duration.

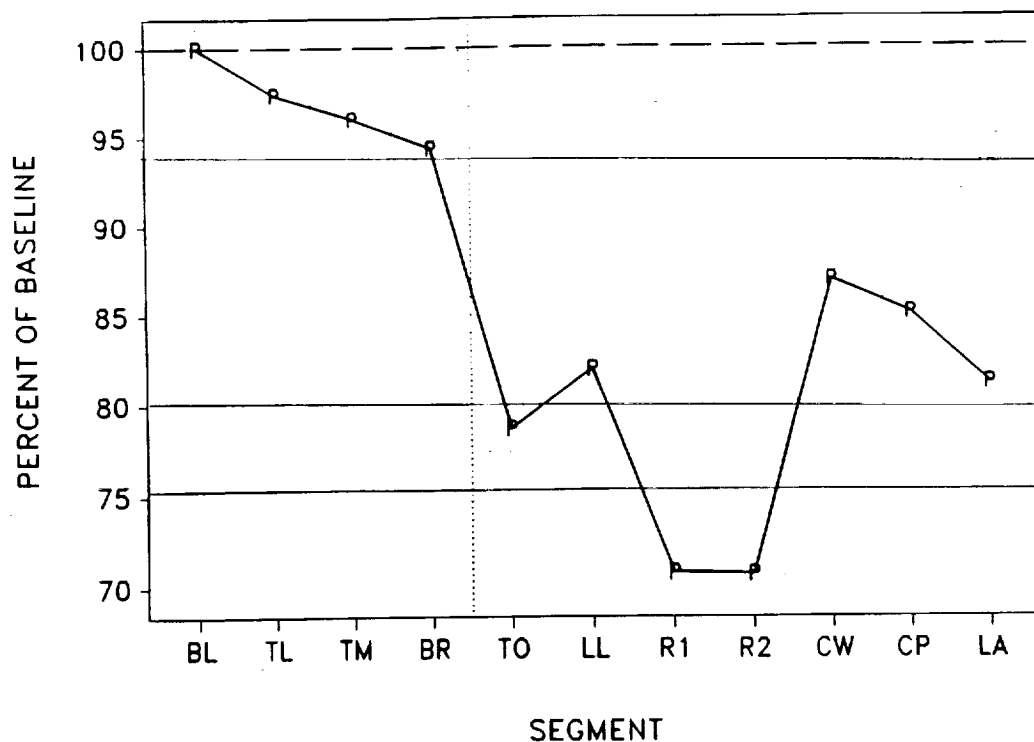


Figure 3. Mean interbeat intervals for 10 F4 pilots. The solid horizontal lines separate segments that are statistically different from one another. Note that there are four groups. The X-axis labels are the same as Figure 2.

These data show that eye blinks are a very good measure of visual demand, with high demand being associated with fewer, faster blinks which reduces the probability of missing important information.

We have used heart rate and eye blinks together to classify flight segments. We took advantage of the unique response patterns of individual crew members to permit classification of the segment of flight. Discriminant analysis was used on the data from each subject to determine the best linear combination of variables to classify the flight segments. We were able to correctly classify the eight selected segments 93% of the time for the F4 pilots and 89 % of the time for the WSOs (Wilson & Fisher, 1991a).

ELECTROENCEPHALOGRAM - EVOKED POTENTIALS

We have used brain evoked potentials to study the changes in brain activity associated with increasing task demands. Evoked potentials are the small changes in the electrical activity of the brain that are associated with processing of information contained in discrete stimuli. We have used standard and topographical methods to follow the time course of the evoked potentials and their topographical distribution over the scalp. The latter involves the recording from 20 electrodes placed over the scalp and using the resulting data to determine the pattern of electrical activity changes over the head as the subject processes information. We have found, in several studies, that the amplitude of the late evoked potential components decreases with increasing task difficulty. We have used several cognitive tasks, including spatial (Wilson, Swain & Davis, 1988), mathematical, linguistic and stimulus degradation tasks (Wilson, Palmer, Oliver and Swain, 1991).

We have also used spectral analysis of the ongoing brain activity to classify the cognitive tasks that the subjects were performing. Discriminant analysis was used to derive linear combinations of the spectral components from 20 electrodes to classify the seven tasks. The data were divided into a training

and test sets and we were able to correctly classify the seven tasks 80% of the time for our eight subjects. This demonstrates that brain activity can be used to determine the nature of the task that subjects are performing (Wilson & Fisher, 1991b). Since it is simple to implement the classifier, it would be possible to perform the classification in real time while the subjects are performing tasks or even flying. This could be a very useful application of brain activity to the determination of operator state in real time.

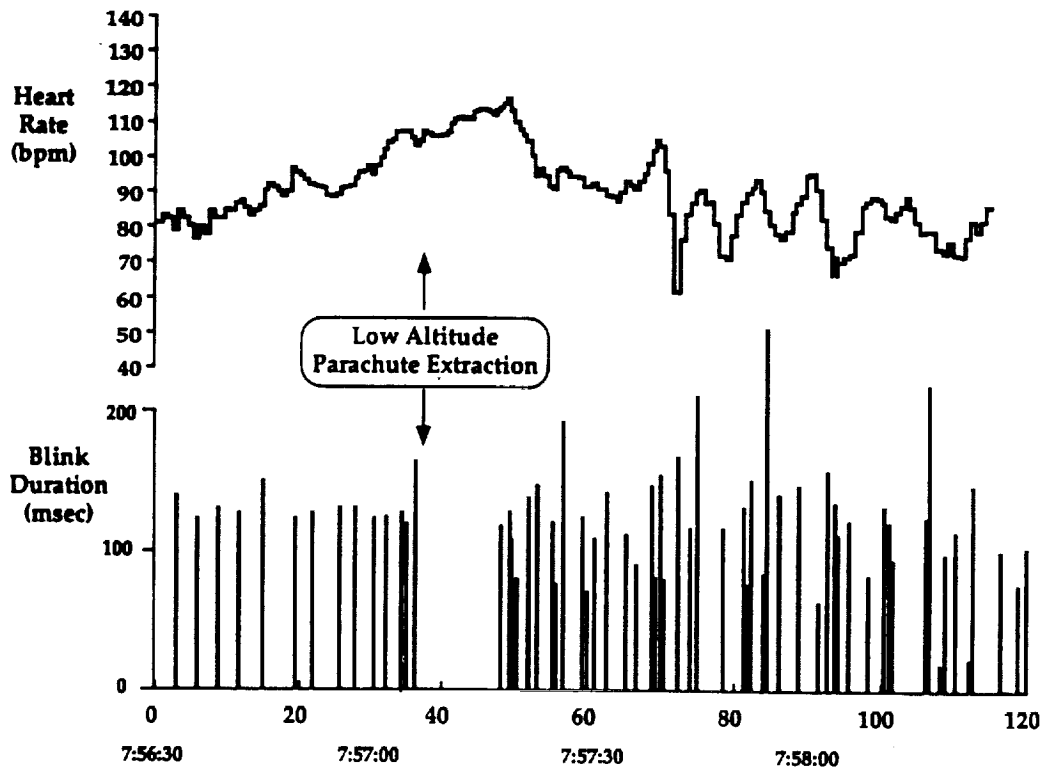


Figure 4. Interbeat intervals, top, and eye blinks, bottom, from a C-130 transport pilot during a low altitude parachute extraction (LAPES). Note that heart acceleration reaches it's maximum following the LAPES. The eye blinks exhibit a regular pattern with even blink durations prior to the LAPES, an inhibition for approximately 10 seconds during the LAPES, followed by a more normal blink pattern following the LAPES.

We have extended the use of evoked potential techniques to the flight environment for the first time (Wilson & Fullenkamp, 1991). Evoked potentials were recorded from pilots while they performed an auditory discrimination task on the ground and while flying. Evoked potentials were recorded during two cruise flight segments (Figure 5). During one segment the pilot was actually flying the aircraft and during the other the WSO was flying the aircraft. The main objective was to demonstrate that evoked potentials could be recorded during flight and the secondary objective was to see if the evoked potentials would provide information concerning the mental workload of the pilots. The first objective was met as was the second. Evoked potentials were recorded and it was found that one component of the evoked activity, the P2, was significantly reduced while the pilot was actually flying the aircraft compared to the ground segment and the other flight segment when the WSO was actually flying and the pilot was primarily a passenger. This opens up the flight environment to the use of evoked potentials as a measure of cognitive activity during the different aspects of flight.

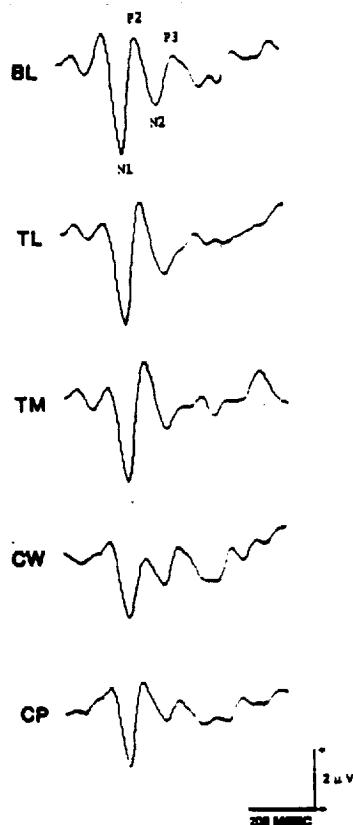


Figure 5. Averaged evoked potentials from auditory stimuli from seven F4 pilots during five segments. The four measured components are labeled, two positive and two negative. The conditions were BL - baseline, tone only, TL - low tracking difficulty, TM - medium tracking difficulty, CW- Cruise, pilot flying, CP - Cruise, WSO flying.

SUMMARY

Laboratory data is required to develop methods and theories of cognitive workload and to develop a database. However, these measures and methods must be validated in "real world" situations, such as flight, so that their applicability to these situations can be tested since all of them will not be useful in the "real world." The examples cited above of blink rate and heart rate demonstrate that laboratory data may not be at all applicable to the "real world." The difference in operator experience and the dynamic range of the physiology means that flight databases must be developed in order to provide a milieu in which flight data can be interpreted. The collection of physiological data during flight is not the problem, the concern now is having a large enough database to provide for proper interpretation.

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