CARDIAC AND EYE ACTIVITY CORRELATES OF SLEEP LOSS IN HELICOPTER PILOTS

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The effects of one night's sleep loss on helicopter pilot's psychophysiology were investigated. This was done to determine if cardiac and eye measures were sensitive to sleep loss during actual flights. Because of the potentially catastrophic errors that can occur when sleep deprived reliable measures to detect this state are needed. If the deleterious effects of sleep loss can be determined prior to performance break down then it should be possible to devise systems to avoid accidents. Ten pilots flew a standard 1.5 hour scenario three times with increasing hours of sleep loss. Heart rate, heart rate variability and eye blink rate were recorded during the three flights. Heart rate and heart rate variability demonstrated statistically significant effects as the sleep loss increased. Heart rate variability declined, especially during the most difficult fight maneuvers at the highest levels of sleep deprivation.

INTRODUCTION

A common problem in operational aviation settings is the fatigue that stems from long duty hours and erratic schedules. Accurate indicators of fatigue could enhance both safety and effectiveness by mitigating increased errors, and in some cases, preventing catastrophic mistakes that might otherwise occur without prior indication of performance degradation. In order to sustain performance and maximize the probability of mission success, reliable, nonintrusive measures of pilot functional state are required. Psychophysiological measures have been suggested as possible indicators of degraded operator functional state (Caldwell, et al., 1994; Wilson, 2002a). Two psychophysiological measures, heart rate and eye blinks, are relative easy to collect and have been shown to be sensitive to fatigue (Stern, Boyer, & Schroeder, 1994; Stern, Walrath, & Goldstein, 1984; Kramer, 1991; Wilson & Eggemeier, 1991). Increasing blink rates and eye closure durations have been associated with fatigue while lowered heart rates and increased heart rate variability have been reported. If these measures are found to be reliable predictors of fatigue states and operational errors, they could be used to prevent accidents and degraded performance. The purpose of this study is to monitor cardiac and eye activity in helicopter pilots during a standard flight scenario while non-sleep deprived and while sleep deprived.

METHOD

Ten UH-60 aviators (9 males and 1 female) served as subjects. The average age of the participants was 31.2 years (range of 26 to 46), and the average flight experience was 1153 hours (range of 300 to 5000).

Subjects completed three days of flights in a specially-instrumented UH-60 helicopter. On the first day, each pilot flew the same standard scenario three times for practice. On the second and third days, each pilot flew the scenario while data were collected. Flights occurred at 2300 hours on the second day and at 0400 hours and 0900 hours on the third day. They did not sleep on the night between the second and third days.

After arriving at the laboratory on the second day the aviators were instrumented for physiological recording. Electrodes were attached to record eye blinks and heart rate (HR). A Cadwell Laboratory Airborne Spectrum 32 telemetry system was used to amplify the signals and telemeter them back to base. The data were bandpass filtered between 0.53 Hz to 100 Hz. A Workload Assessment Monitor system was used to analyze the data to produce HR and blink rate. Heart rate variability (HRV) was calculated using the Delta Biometrics MXedit software. Artifacts in the HR interbeat intervals were corrected prior to calculation of HRV. Two bands were assessed, the so called mid-frequency band, 0.06 Hz to 0.14 Hz, and respiratory sinus arrhythmia band (RSA), 0.15 Hz to 0.5 Hz. Data from two minute segments were analyzed from each of the 17 flight segments, including baselines (described below). These data were analyzed with ANOVA and paired t-tests.

Prior to each flight, while in the helicopter, the pilots rested with eyes open and eyes closed to provide baseline records. They then flew an approximately 1.5 hour scenario. A safety pilot was in the co-pilot's seat at all times and was responsible for take-off for each flight. After take-off the subject pilots flew 15 segments which included a climb, a descent, two right and two left standard-rate turns (RSRTs and LSRTs), a right descending turn (RDT), a left climbing turn (LCT), six straight-and-level (SL) maneuvers, and an instrument landing system (ILS) approach. See figure 1 for the sequence used.

RESULTS

A comparison of the HRs during the three flights showed that the 0400 flights were associated with significantly lower HRs than the 2300 and 0900 flights (figure 1). Comparisons of the HRs during the different segments of the 2300 flights showed that the HRs during the straight descent and the last S/L were significantly lower than the HRs during 8 of the other flight segments. HRs during the last 5 segments of the 0400 flights were significantly lower than many of the earlier segments. HR during the S/L immediately following the left climb 540-degree SRT in the 0900 flight was significantly lower than the HRs from 9 other segments. The left-climbing 540-degree SRT was associated with significantly higher HRs than five of the later segments in the 0400 and 0900 flights but not in the 2300 flight. During the 0400 flight the HRs during the right-descending 360-degree SRT and the right 360-degree SRT were significantly higher than five and four of the following segments, respectively.

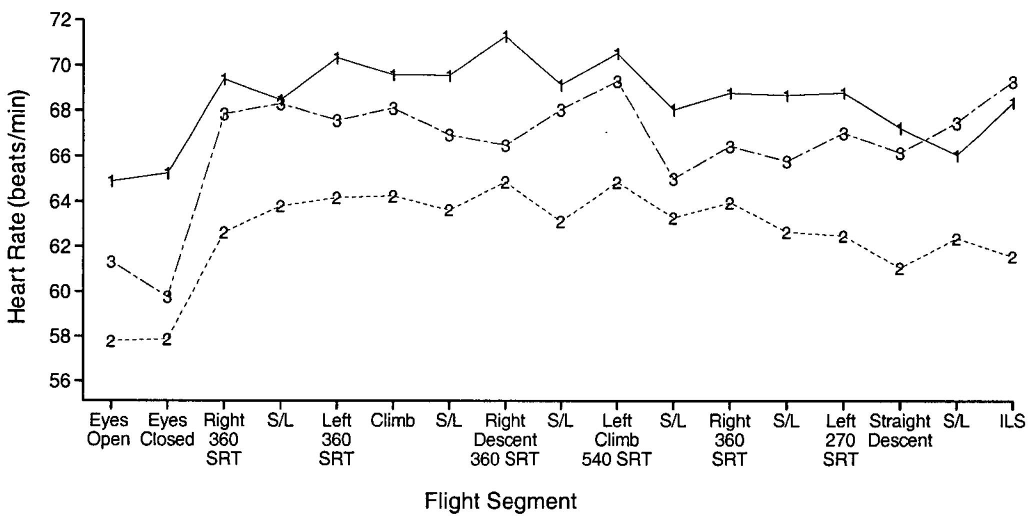

Figure 1. Mean heart rates for each of the three flights. See method section for explanation of flight segments. 1 – 2300 flight, 2 – 0400 flight, 3 – 0900 flight.

Across all three flights the RSA during the left-climbing 540-degree SRT was significantly lower than the values obtained in the 11 other flight segments. At 0400 the RSA during the left-climbing 540-degree SRT was significantly lower than 5 of the other flight segments while at 0900 RSA it was significantly lower than 7 other segments. RSA during the last S/L was significantly higher than during 8 of the other 14 flight segments. During the 0900 flight the ILS RSA values were significantly lower than nine of the other fourteen flight segments. For the mid-frequency band, larger differences in HRV were found between the S/L and maneuvering segments. Over all, HRV showed larger numbers of significant differences between segments during the 0400 and 0900 flights.

Blink rates during the eyes open baseline segment were highest for the 0900 flight, fewer at 0400 and fewest at 2300. Blink rates were significantly higher during the 0900 flight for the eyes open, climb, straight descent and final S/L segments. The blink rate during the 0900 flight for the left-climbing 540-degree SRT was significantly lower than 6 of the other flight segments. Blink rates for the other 2 flights were essentially statistically identical.

DISCUSSION

These data show that the effects of sleep loss for only one night are evident in the heart rate data. The lower HRs during the 0400 flight compared to the other two flights no doubt represent the expected circadian low during this time. Body temperature and other physiological measures are markers for this circadian trough. While primarily of physiological origin, the reduced heart rates occur at times that are known to be associated with increased errors and accidents. As the sleep loss continued, more significant effects among flight segments were seen in the later stages of the flights. Further, the left-climbing 540-degree SRT had higher HRs on the last two flights showing the interaction of fatigue and workload. This was the most difficult maneuver for the pilots and the effects of sleep loss required the pilots to muster additional cognitive resources to accomplish the maneuver. The significantly lowered HR during the S/L segment which immediately followed the climbing 540-degree SRT also underlines the difficulty of executing this maneuver in the sleep loss state. This significant lowering of HR during the subsequent S/L segment could well be due to a rebound relaxation following execution of the very difficult climbing 540-degree SRT.

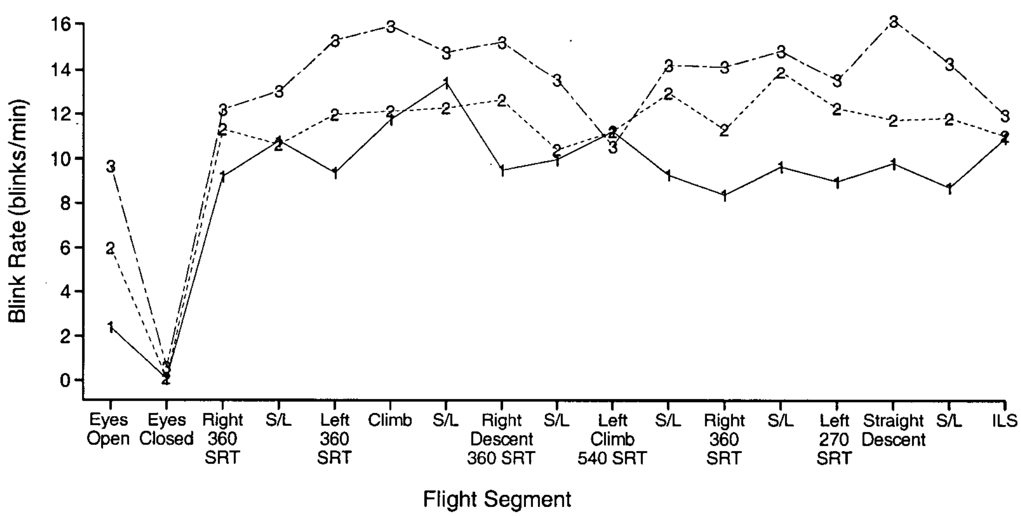

Figure 2. Mean blink rates for each of the three flights. See method section for explanation of flight segments. 1 – 2300 flight, 2 – 0400 flight, 3 – 0900 flight.

The changes in the RSA band of the HRV provides further evidence of the cognitive effects of sleep loss. Decreased HRV is seen as an index of increased cognitive effort (Kramer, 1991; Wilson & Eggemeier, 1991). The left-climbing 540-degree SRT was associated with significantly reduced RSA. The level of the HRV during this maneuver decreased over the three flights with the 0900 flight associated with the most significant differences from other segments. The final maneuver, ILS, during the 0900 flight was significantly lower than nine of the other 14 flight segments. The S/L preceding the ILS was significantly larger than eight of the other 14 flight segments. These RSA data illustrate the broad HRV swings produced by sleep loss, especially at the end of the last flight. The sleep loss caused the pilots to recruit more cognitive resources during the difficult maneuvers, left-climbing 540-degree SRT and ILS. The results of the mid-frequency band of the HRV further supports this view by exhibiting larger changes between the difficult maneuvers and the S/L segments (which are easy) during the last two flights.

The effects of sleep loss on eye blinks was evident only during the eyes open segments on the ground and not during the flights. This lack of blink-rate effect during the flights was no doubt due to the high visual demands of piloting (Wilson, 2002b). The pilots were required to maintain visual attention both inside and outside the cockpit to sustain safe flight during all segments. Thus, there may have been a ceiling effect on the number of blinks. However, during the most difficult maneuver, the left-climbing 540-degree SRT, there was a significant reduction in blink rates during the 0900 flight. This may be associated with increased cognitive demands to correctly execute this difficult maneuver with reduced cognitive resources.

These results demonstrate the value of HR, HRV and eye blinks to assess the effects of sleep loss in helicopter pilots. These data suggest that these measures could prove valuable in systems designed to detect deleterious effects of fatigue. Because the pilots in this study did not make overt mistakes the psychophysiological data may serve as early warning markers.

REFERENCES

Caldwell, J.A., Wilson, G.F., Cetinguc, M., Gaillard, A.W.K., Gundel, A., Lagarde, D., Makeig, S., Myhre, G. & Wright, N.A. (1994). *Psychophysiological assessment methods. Report*, AGARD-AR-324, Neuilly sur Seine.

Kramer, A.F. (1991). Physiological metrics of mental workload: A review of recent progress. In Damos, (Ed.) *Multiple-task Performance* (London: Taylor and Francis), pp. 279-328.

Stern, J. A., Walrath, L. C., & Goldstein, R. (1984). The endogenous eyeblink. *Psychophysiology*, 21, 22-33.

Stern, J. A., Boyer, D., & Schroeder, D. (1994). Blink rate: A possible measure of fatigue. *Human Factors*, 36, 285-297.

Wilson, G. F. & Eggemeier, F. T. (1991). Physiological measures of workload in multi-task environments. In D. Damos, (Ed.) *Multiple-task performance* (pp. 329-360). London: Taylor and Francis.

Wilson, G. F. (2002a). Psychophysiological Test Methods and Procedures. In S. G. Charlton and T. G. O'Brien, (Eds.), *Handbook of Human Factors Testing & Evaluation, Second Edition* (pp. 127-156). Lawrence Erlbaum Associates, Inc.

Wilson, G. F. (2002b). An analysis of mental workload in pilots during flight using multiple psychophysiological measures. *International Journal of Aviation Psychology*, *12*, 3-18.