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Assessment and Classification of Cognitive Decrements Associated with High Workload and Extended Work Periods in a UAV Setting

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14. ABSTRACT
The present study investigated high workload and time-on-task effects through the assessment of performance and physiological measures during the continuous performance of a complex uninhabited air vehicle UAV task. This study systematically explored the effects of time-on-task, while also incorporating a variety of workload conditions designed to simulate an actual UAV operation. Subjective sleepiness and workload were monitored, as well as performance, on a psychomotor vigilance task. Electroencephalographic data were collected in order to establish physiological evidence of fatigue due to time-on-task. The results of this study demonstrated that performance remained stable throughout the 4-hour continuous mission on all workload conditions. In addition, no physiological evidence of fatigue was identified.

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BACKGROUND

Uninhabited air vehicles (UAVs) are playing an increasingly important role in Air Force combat and reconnaissance operations and UAV operators must rely on a wide range of cognitive skills in order to successfully accomplish their missions. UAV operators must vigilantly perform vehicle maintenance tasks while simultaneously flying the vehicle, navigate through space, download radar images, discriminate targets from non-targets, and subsequently release weapons--all within very short time frames. Thus, the task itself can be quite demanding, and operators must be able to cope with a wide range of workload conditions. High levels of cognitive demand can lead to errors which can result in catastrophic outcomes (Wilson, 2003). Increasing our knowledge of the effects of the various levels of cognitive demand encountered by Air Force operators would allow room for mitigations to avoid such errors.

Additionally, UAV pilots must endure lengthy work schedules. As a result, the quality of performance can be adversely affected. Tvaryanas, Thompson, and Constable (2006) recently reported that MQ-1 Predator operators evidenced significant decrement in mood, cognitive, and vigilance performance over the course of real-world combat support missions. While these effects were likely exacerbated by shift-work scheduling factors, the finding that crews routinely experienced moderate to high levels of on the job boredom raises the possibility that “hours-on-task” may in and of itself be responsible for operator impairments. Unfortunately, there have been no investigations of the extent to which generalized UAV operator performance deteriorates as a function of time-on-task, much less the exact nature of the cognitive skills responsible for any observed decrements, and/or the extent to which these performance decrements can be predicted in a timely fashion.

According to Broadbent (1979) and Meijman (1991) time-on-task affects performance through an individual’s subjective aversion to invest further effort. This is due to the maintenance of cognitive control that is required to sustain performance during prolonged task engagement (Van der Hulst, Meijman, & Rothengatter, 2001). Hockey (1997) explained that strategy shifts may occur, as time-on-task increases, as a mechanism for coping with the increased demand of cognitive control. Such strategic shifts occur in an attempt to reduce the amount of effort invested in the task while also attempting to retain stable levels of performance. The ability to maintain performance under prolonged activity by using less effortful strategies may be efficient for simple tasks, but the successful performance of complex tasks that require a high level of attention may be compromised as effort is reduced. For example, Haga, Shinoda, and Kokubun (2002) found that performance on a zero and first order tracking task, coupled with a monitoring task, did not deteriorate as time-on-task increased (each participant completed 3 test blocks of 10 minutes, 20 minutes, and 30 minutes). However, second-order tracking, as well as the paired monitoring task, deteriorated as a function of time-on-task. As a result, these authors concluded that time-on-task effects are specific to high workload conditions.

Boksem, Meijman, and Lorist (2005) performed an event-related potential (ERP) study with time-on-task operationalized as 3 hours of sustained performance on a memory set task. The memory set task required participants to respond to relevant items but not to respond to irrelevant items. The results of this study revealed that participants reported significantly more aversion to the task as the time-on-task increased. In addition, participants on average slowed down, missed more targets, and responded with more false alarms with increasing time-on-task. More importantly, ERP analysis indicated that performance differences were not due to attention allocated to relevant stimuli, but that changes in performance may be due to increased attention to irrelevant stimuli. Boksem, et al., (2005) concluded from this study that the time-on-task may affect performance through the inability to allocate resources to task-relevant information. The success of proper resource allocation is critical in high workload conditions, such as UAV operations.

It is obvious from this brief review that both high mental workload and time-on-task can have very deleterious consequences for operator performance. The interactive effects of these two stressors have not been systematically studied with operators of complex systems, though such effects have been noted by operators for several years. In fact, a risk assessment of 19 sonar operators revealed that the top critical factors responsible for accidents during sonar operations include boredom, fatigue, and operator workload (Mackie, Wylie, & Smith, 1985).

The present study investigated the effects of high workload and time-on-task through the assessment of performance and physiological measures during the continuous performance of a complex UAV task. It will also provide a methodological procedure and set of reference data useful for the future study of interventions which may mitigate decrements in complex, operationally-relevant cognitive performance.

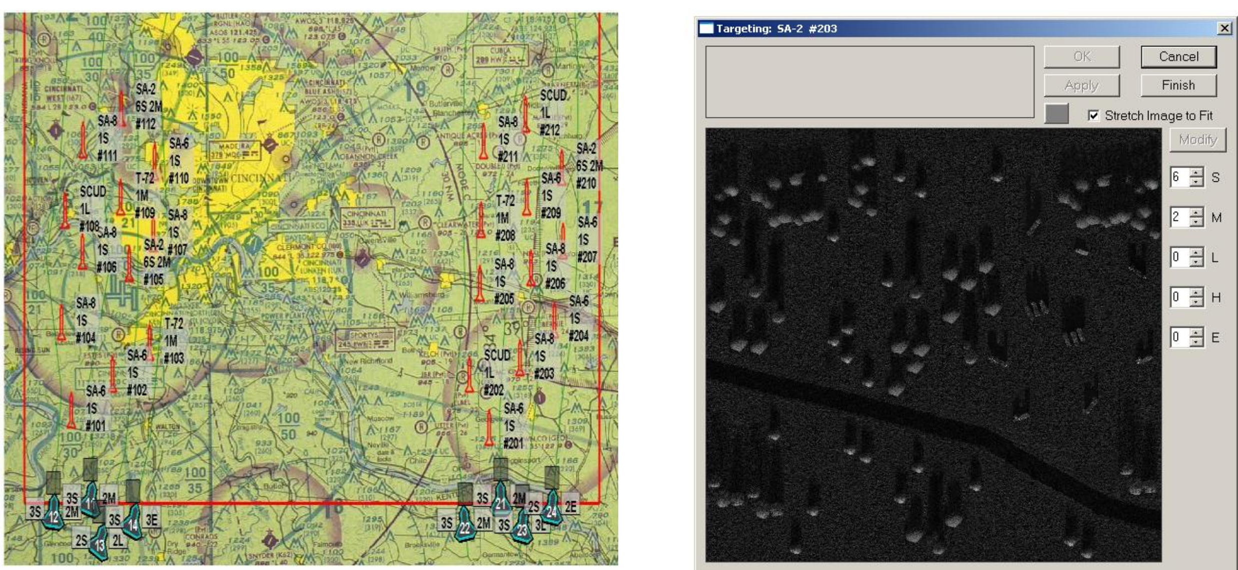
This experiment will leverage the considerable expertise of Dr. Glenn Wilson (retired Senior Research Psychologist of the Air Force Research Laboratory, Human Effectiveness Directorate), and Dr. J. A. Caldwell of Archinoetics, LLC. In terms of direct military relevance, this effort may help provide scheduling guidance to the UAV community. From a research standpoint, this effort will explore the feasibility of classifying operator state, in real time, under the demands of a typical work-setting. It will also expand our knowledge of the specific cognitive skill decrements responsible for overall task performance decrements, while formalizing and validating a methodological procedure for rapidly assessing the efficacy of novel performance-optimization strategies (i.e., mammalian target of rapamycin (mTOR) signaling modifiers and/or other metabolic/pharmacologic interventions being developed by the Applied Biotechnology Branch of the Human Effectiveness Directorate of the 711th Human Performance Wing and possibly others).

METHOD

Materials

This research was conducted at the Operator and Assessment Support Interface System (OASIS) Laboratory, building 33, room 229, Area B, WPAFB. General Dynamics provided support to this research under contract number FA 8650-04-C-6443, Rich Doerr, 255-8162, rich.doerr@wpafb.af.mil. The Oak Ridge Institute for Science and Education, under Contract Number AFRLHE9981MISC, also provided support.

Several performance and subjective measures were used. The *H2O UAV simulation*, with software developed by the Boeing Phantom Works, was the main task performed by the subjects. During this task, operators completed full Suppression of Enemy Air Defense missions with multiple UAVs while the vehicle data and the inputs from the operator were recorded. The *H2O* is a complex cognitive task in which participants are required to fly a preplanned bombing mission, upload radar images, select targets, and release weapons while simultaneously monitoring mission status. These tasks tapped skills such as sustained attention, visual search, visual memory, reaction time, planning, and judgment. Figure 1 illustrates the map interface that was presented to the participants. Figure 1 (a) shows a 2-fly scenario where two sets of four UAVs are to be monitored. The present study utilized both a 1-fly (low workload) and a 3-fly (high workload condition). In addition, a monitoring condition was included where one set of four UAVs were flying, but only one to three targets appeared during the scenario. Figure 1 (b) is an example of a Synthetic Aperture Radar image that appeared once the participant unloads the image.



(a) (b)

Figure 1. H2O UAV Simulation (a) map interface and (b) SAR image

Vigilance performance was assessed using the *Psychomotor Vigilance Task (PVT)*, a portable simple reaction time test known to be sensitive to sleep loss (Dinges et al., 1997). The PVT requires sustained attention and discrete motor responses. The 8" x 4.5" x 2.4" portable, battery-operated device visually displays numbers counted up by milliseconds in a window. The stimulus is presented for up to 1 minute (60,000 msec), allowing the participant to respond. The participant presses a microswitch which allows reaction time to the stimulus to be recorded. The interstimulus interval varies randomly from 2 to 12 seconds. The data are stored on a computer and reduced by custom software for future analysis.

Subjective sleepiness and alertness were measured via the *Visual Analog Scale* (VAS) (Penetar et al., 1993). The VAS required participants to indicate the points on different lines that corresponded to his/her subjective sleepiness and alertness on a specified continuum at the time the test was taken.

Subjective workload was measured via the NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988). The NASA-TLX requires participants to indicate on a 100 point scale in 5-point increments his/her subjective workload on six scales (mental demand, physical demand, temporal demand, effort, frustration, and performance). This scale has very high reliability ($r = .83$).

The subjects' electrical brain activity was recorded from electrodes placed on their scalps (should you name the sites?). Eye activity was monitored from electrodes placed above and below one eye and near the outside canthus of both eyes. Heart activity was monitored by two electrodes placed on the subject's chest. A Cleveland Medical BioRadio 110 telemetry device was used to collect the data.

Wrist monitors (Ambulatory Monitoring, Inc., Ardsley, NY) were used to track sleep/activity rhythms in a relatively unobtrusive fashion. In this study, the wrist monitors recorded sleep/wake activity for two days and nights prior to the testing day in order to ensure that each participant was well rested prior to data collection.

Participants

Ten participants volunteered for this study and completed the experiment. Two individuals' data were not included in the analyses. Several technical issues, occurring during data collection for one individual, caused the data collection session to extend 2 hours beyond what was normal. Since the experimenters felt that these data would compromise the time-on-task objectives of the study, this individual's data was not included in the analyses. The other set of data was excluded because an adverse event caused the data collection to be incomplete. This adverse event was reported and documented with the Institutional Review Board. Thus, 8 participants (3 female and 5 male) were included in the following analyses. Their ages ranged from 20-36 with an average age of 27.5. All participants worked a normal daytime schedule that was verified by the actigraph data recorded 2 days and nights prior to testing. On data collection days, subjects were free of medications which may affect alertness, vigilance, or cognitive abilities (including caffeine and sports drinks).

No special qualifications were required except that the subjects had full use of their arms and legs, and that their self reported vision was approximately 20/20, corrected or uncorrected. Requirements indicated that they had no history of neurological disorder or drug use that is known to compromise their central or peripheral nervous systems.

Subjects were paid (General Dynamics) or unpaid volunteers (Department of Defense employees). Paid volunteers were recruited through General Dynamics (GD), an AFRL contractor that has provided research subjects for previous experiments. Maryann Barbato, GD subject manager, (937-255-3660, ext. 322, maryann.barbato@wpafb.af.mil), recruited from GD's subject data base. Subjects were called and given an opportunity to accept or deny participation in the study. In addition, a mass email was sent through the Wright-Patterson Public Affairs Office to the Air Force Institute of Technology students. The email was generated by the study investigators and forwarded to the Public Affairs Office for distribution via a generic email. The text in this email is shown below. Paid participants were compensated $15/hour for travel and inconvenience.

> <u>Subject recruitment brief</u>: "The U.S. Air Force Research Laboratory (AFRL) is conducting a study in which participants will be tested on the ability to sustain attention during an extended Unmanned Ariel Vehicle mission. Currently, there is no indication of whether the length of duty for UAV operators exceeds the human capacity of extended duty and whether substantial errors will result from this lack of vigilance. The results of this testing may provide the military and scientific communities with information that could change the operational task environment for UAV operators. This study can lead to efforts related to other time-on-task studies as well as display design studies that may allow for operators to work extended hours while maintaining optimal performance.
>
> Volunteers will be asked to come to the lab for extensive training on basic UAV operations. The UAV tasks require participants to fly a preplanned bombing mission, upload radar images, select targets, and release weapons while simultaneously monitoring mission status and intervening in the event of system failures. These tasks tap skills such as sustained attention, visual search, visual memory, reaction time, planning, and judgment. During the experimental, 6 hour testing session, cardiac reactivity data as well as electroencephalographic data will be collected during several extended missions that vary in difficulty."

The proposed effort took place in two phases: A training phase and a testing phase. Phase 1 was composed of a training phase that included 10-20, 2-hour practice sessions specifically on the H2O UAV simulation. Training was completed once participants could maintain a performance criterion of 80% of target hits and 80% of Synthetic Aperture Radar (SAR) completions on the high workload scenario. On the last training session, participants performed the PVT for one required practice session. Phase 2 consisted of the testing phase (one testing session for each subject) that began at 0800 and continued for a period of ~6 hours.

Procedures

Following several sessions of task train-up, participants were tested in one prolonged test session, beginning at 0800. During testing, participants performed the H2O UAV task for 4 hours which was broken into 4, 1-hour sessions. Each 1-hour H2O task consisted of a monitoring segment, a low workload segment, and a high workload segment. The NASA-Task Load Index (NASA-TLX) was administered at the end of each of these three segments, and the PVT and VAS were completed at the end of hour-session. Physiological data was collected continuously throughout the testing day.

Participants signed consent forms and passed a medical records review conducted by a flight surgeon prior to admission into the study. All participants refrained from consuming alcoholic and caffeinated beverages throughout the study since they are known to affect sleepiness/alertness. This restriction is commonly applied to fatigue and time-on-task studies in order to reduce any potential experimental confounds that ingestion of these substances may cause. Since testing only took place during one day over a 6 hour period, side effects associated with alcohol and caffeine cessation were not expected to occur; however, a mild headache and slight irritability were possible. The H2O UAV simulator task was presented via standard computer monitors, and the subjects interacted with the task with a standard mouse and keyboard. The physiological measures were recorded using non-invasive procedures and did not constitute a medical risk to the subjects aside from mild skin irritation that may occur where the electrodes were placed. However, in once instance, a participant had an allergic reaction during the experiment. It was determined by the medical monitor that the allergic reaction was due to either the adhesive from the electrode snap clothes or the conductive gel. The experiment was terminated once the allergic reaction was apparent. The adverse event report was filed with the Wright Patterson Institutional Review Board. Since this participant was the last enrolled participant, changes to the testing procedures did not take place. However, future protocols required exclusion of participants who have a history of urticaria (hives), atopy, or eczema. No drugs or medical procedures were involved in this experiment, and voice contact with the experimenter was maintained at all times. Data collected in this study were treated to protect the subjects' privacy. Data presented or published will not identify individual subjects. Results of this study are available to the subjects upon request.

The Medical Monitor appointed a Medical Observer to be available by telephone throughout the experiment. All study personnel received written instructions on the mechanism for responding to urgent and emergent medical conditions. These instructions included information on the appropriate medical disposition of participants who become injured or ill while participating in the research protocol. In the case of a true emergency, the local EMS was to be called for ACLS or trauma support and transported to definitive medical care. All others, with lesser adverse medical outcomes, were to be transported to an appropriate military or civilian medical facility for evaluation and treatment as directed by the Medical Monitor or Medical Observer. The Medical Monitor overseeing the protocol was to be notified of any serious adverse event resulting from the research exposure within 12 hours. All illnesses or injuries occurring in participants while participating in this experiment, but not causally related to the experiment, were to be brought to the attention of the Medical Monitor within 48 hours. Aside from the single, reported adverse event, no other injuries or illnesses occurred.

RESULTS

For assessing the effects of time-on-task, a series of mixed-model analysis of variance tests (ANOVAs) were conducted. Time-on-task and level of workload were the main independent variables of interest. Among those assessed for their ability to remain stable as a function of time-on-task and workload were: Performance on the UAV mission and the psychomotor vigilance task, subjective sleepiness, fatigue, and workload, and mean power for the alpha band, theta band, beta band, and the delta band on five sites (4 sessions X 3 workload levels).

For the first set of analyses, a mixed-model ANOVA was run on the percentage of targets hit, the percentage of SAR images captured, the percentage of distracters hit, and the number of false rejections (the number of images that were discarded for not containing a target, even though a target was present), as a function of the time-on-task and workload repeated factors. Although the percentage of distracters that were hit appeared to increase for during the high workload conditions of the last two sessions, none of the performance metrics actually resulted in a significant change from session to session or as a function of workload. Figure 2 shows the percentage of distracters hit, for the high workload condition, over the four testing sessions. It can be concluded, therefore, that performance remained stable for the simulated UAV mission for the 4-hour mission duration.

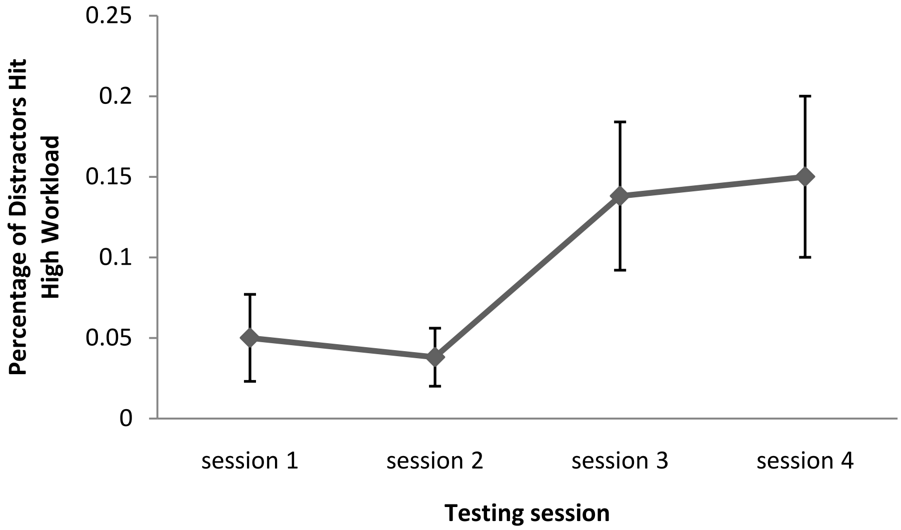


Figure 2. Percentage of distracters hit for the high workload condition as a function of time-on-task

The next set of analyses included mixed-model ANOVA's on the subscales of both the NASA TLX and the Visual Analog Scale with time-on-task and workload as fixed, independent factors. Again, none of the subscales revealed significant changes, though the high workload condition did show increasing scores on certain subjective workload metrics (temporal demand, effort, and mental demand), as shown in Figures 3, 4, and 5.

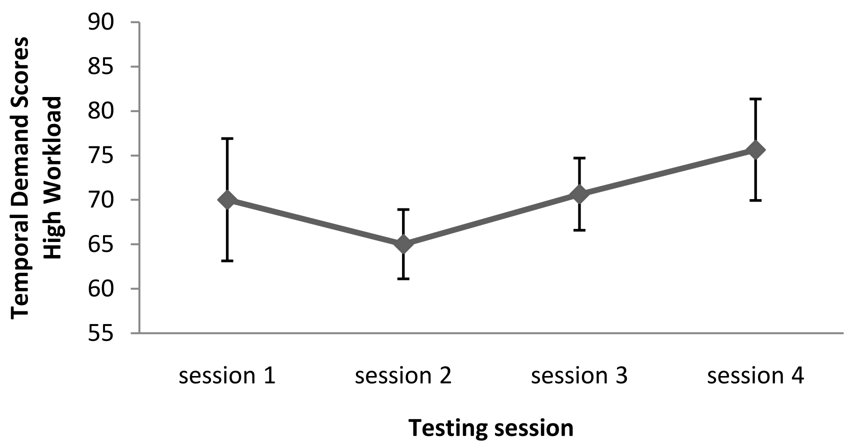


Figure 3. Temporal demand for the high workload condition as a function of time-on-task

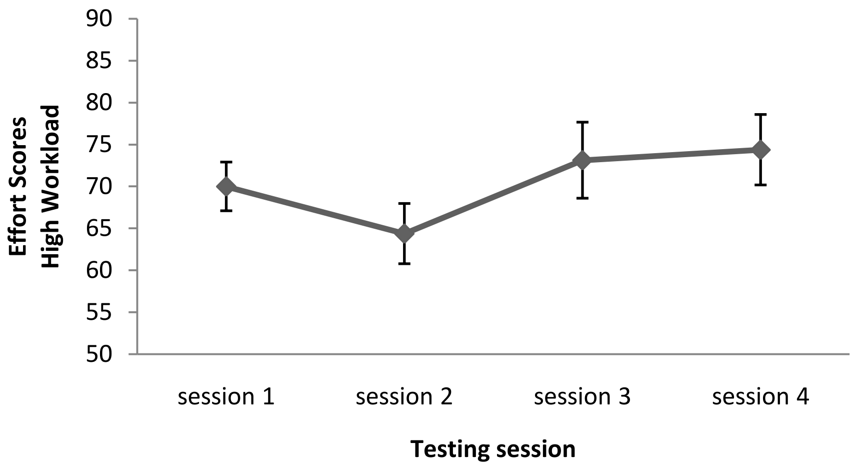


Figure 4. Effort scores for the high workload condition as a function of time-on-task

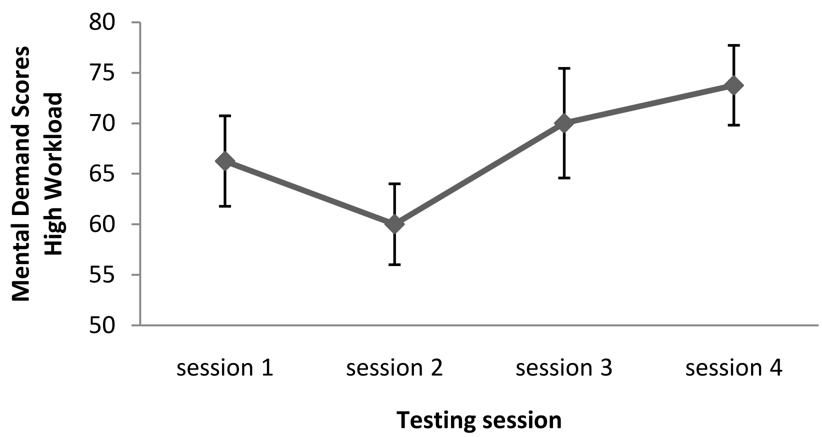


Figure 5. Mental demand for the high workload condition as a function of time-on-task

Next, mixed-model ANOVA's were conducted on the mean power for sites Fz, Cz, Oz, Pz, and O2 for all bands (beta, alpha, theta, and delta) with time-on-task and workload as fixed, independent factors. Again, no interactions or main effects for session were found. Thus, the current data is also lacking physiological evidence of fatigue. Figure 6 illustrates a main effect for task, $F(4, 100) = 22.25$, $p < .001$, where the baseline average power for site Oz, alpha band was significantly higher than all other tasks.

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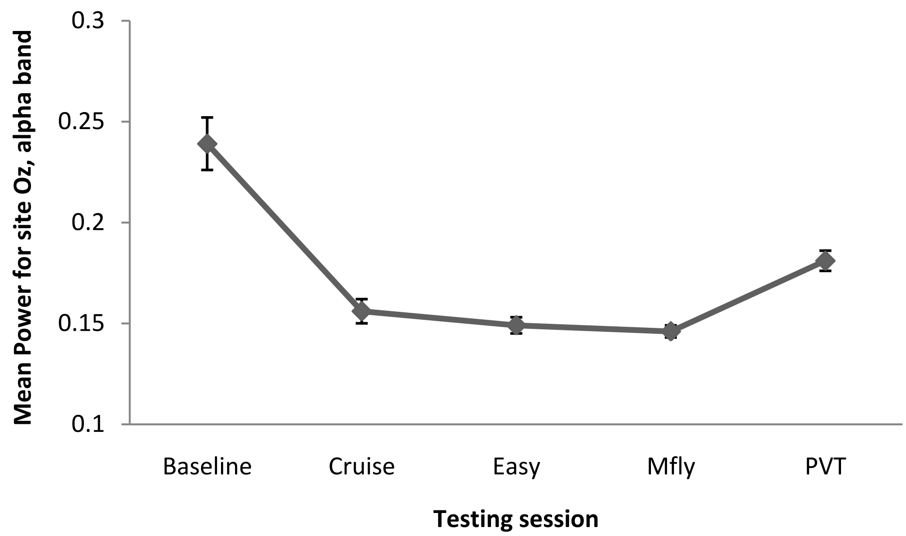

Figure 6. Average power for site Oz, alpha band as a function of task and session

A mixed-model ANOVA was also performed on the inter-beat interval (IBI) data as a function of task and session. A main effect for session was found, $F(3, 63) = 3.83$, $p = 0.014$, with session 3 exhibiting a higher IBI than session 1 (Bonferroni post-hoc comparisons were performed). Figure 7 shows this main effect for session. You can see from the figure that heart rate slightly increased for the monitoring and low workload tasks up to session 3 and remained high during session 4. For the PVT, heart rate increased during session two, but then decreased. The high workload condition exhibited an early increase (session 2) and remained high for the duration of the experiment.

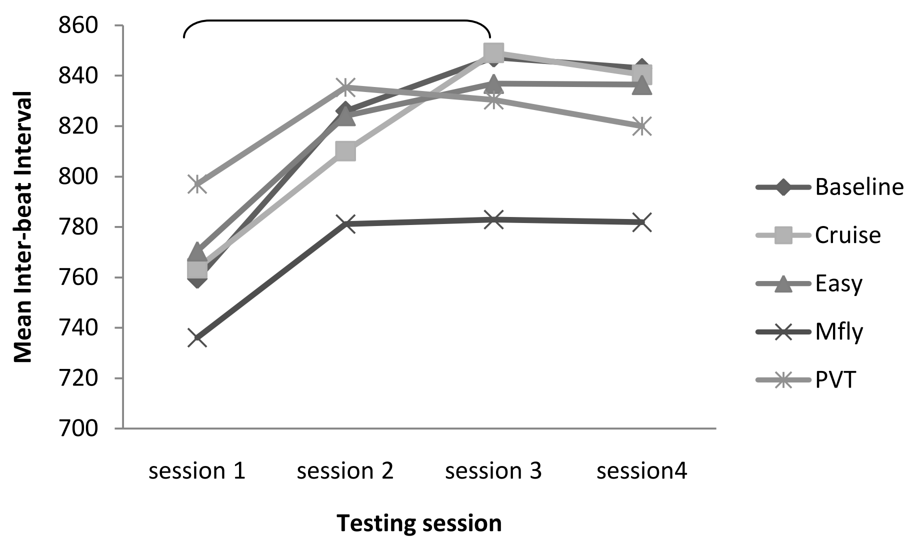

Figure 7. Average inter-beat interval as a function of task and session

CONCLUSIONS

The current study found that performance on a Suppression of Enemy Air Defense mission remained stable after 4 hours of continuous operations. In addition, no physiological evidence of fatigue was identified as a function of time-on-task. These findings suggest that UAV operators are capable of performing a mission for up to 4 hours without extreme performance decrements.

There are several possible explanations why time-on-task effects were not found and why UAV operators may not encounter the types of errors typically identified in vigilance-type occupations. The current experiment was designed so that the workload levels were systematically varied in an attempt to simulate actual operations. The varying workloads may have helped the operators stay engaged in the task and prevented time-on-task effects from occurring. Boksem, Meijman, & Lorist (2005) found that during a 3-hour, low workload task, physiological evidence of fatigue was identified (decreased beta and increased alpha for EEG output), and performance significantly decreased. This may actually be what happens during continuous low workload reconnaissance operations. However, the operational environment is more comprised of a range or workload levels that change in an unpredictable pattern (National Research Council, 1993). For example, a high workload task followed by a low workload task can actually lead to performance enhancement.

Another reason why a time-on-task effect may not have been found in the present study is that performance on each scenario was not analyzed on a moment-to-moment basis. Basner, Rubinstein, Fomberstein, Coble, Ecker, Avinash, and Dinges (2008) performed a study on simulated baggage screening while evaluating the effects of both sleep deprivation and time-on-task. While an interaction was not found, their study found that time-on-task effects occurred with individuals becoming more conservative and responding faster toward the end of the task. The baggage screening task lasted approximately 25-30 minutes, which is the typical length of a vigilance task. The combination of the UAV simulation not being a traditional vigilance setting combined with the short length of 15 minutes per task makes it a poor candidate for vigilance testing. In addition, the present study's metrics averaged performance across the 15 minutes rather than on a moment-by-moment basis.

Future research should replicate the present study with longer missions and with the capability of assessing moment-to-moment changes within a scenario. In addition, it may also be important to assess performance changes as a function of workload transition. For example, performance may improve on high workload tasks following low workload tasks, but not following other high workload tasks. The National Research Council (1993) discusses the complexities of workload transition effects and recommends systematic evaluation in order to establish its affect on operations.

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