ORIGINAL RESEARCH

Controlled Breaks as a Fatigue Countermeasure on the Flight Deck

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Background: A major challenge for flight crews is the need to maintain vigilance during long, highly automated nighttime flights. No system currently exists to assist in managing alertness, and countermeasure options are limited. Surveys reveal many pilots use breaks as an in-flight countermeasure, but there have been no controlled studies of their effectiveness. ***Hypothesis:*** We hypothesized that brief, regular breaks could improve alertness and performance during an overnight flight. ***Methods:*** A 6-h, uneventful, nighttime flight in a Boeing 747-400 flight simulator was flown by fourteen two-man crews. The 14 subjects in the treatment group received 5 short breaks spaced hourly during cruise; the 14 subjects in the control group received 1 break in the middle of cruise. Continuous EEG/EOG, subjective sleepiness, and psychomotor vigilance performance data were collected. ***Results:*** During the latter part of the night, the treatment group showed significant reductions for 15 min post-break in slow eye movements, theta-band activity, and unintended sleep episodes compared with the control group. The treatment group reported significantly greater subjective alertness for up to 25 min post-break, with strongest effects near the time of the circadian trough. There was no evidence of objective vigilance performance improvement at 15–25 min post-break, with expected performance deterioration occurring due to elevated sleep drive and circadian time. ***Conclusions:*** The physiological and subjective data indicate the breaks reduced nighttime sleepiness for at least 15 min post-break and may have masked sleepiness for up to 25 min, suggesting the potential usefulness of short-duration breaks as an in-flight fatigue countermeasure.
Keywords: breaks, fatigue, flight crews, EEG, vigilance, alertness.

FOR PILOTS, LONG FLIGHTS IN modern aircraft are characterized by extensive monitoring, reduced interaction with airplane systems due to high automation levels, and limited social interaction. The flight deck typically has a low light level during night flights, steady background noise, and permits only limited environmental manipulations. Pilots often operate in this environment with significant underlying sleep pressure resulting from acute sleep loss, the presence of a sleep debt, a long period of continuous wakefulness, and/or long duty hours. Under these conditions, a pilot is vulnerable to boredom, complacency, attentional lapses, and even uncontrolled sleep. Surveys, observational data, and anecdotal reports reveal that, in fact, it is not uncommon for flight crews to experience unintentional sleep episodes while flying (5,14,24). Even when outright sleep fails to occur, the underlying sleepiness exposed by this soporific environment can lead to compromised vigilance and impaired performance. If the flight occurs at night, when the biological timing system is programming the body for sleep, fatigue and sleepiness levels increase even further. Serious performance impairment can result, with a significant reduction in the safety margin. Performance degradation, including vigilance lapses and brief sleep episodes have been documented in long-haul crews flying at night (25).

Fatigue is recognized as a major concern by pilots who must fly at night and sleep during the day. No system currently exists to assist pilots in managing their alertness. Furthermore, behavioral countermeasures to fatigue are limited by the Federal Aviation Regulations (FARs), safety concerns, and the flight deck environment itself. For example, while a 26-min nap has been demonstrated to result in significant improvements in subsequent physiological alertness and psychomotor performance (25), cockpit napping is not currently sanctioned. Taking a break from flying (and perhaps stretching and/or walking) is one of the few countermeasures feasible in the flight deck environment and potentially available to sleepy crews flying at night. However, FARs mandate that pilots remain seated throughout the flight, with few approved exceptions*. Despite these restrictions, there are anecdotal reports from pilots indicating that many take brief, out-of-the-seat breaks as a countermeasure during fatiguing flights.

Several Canadian studies noting the effects of breaks in sleep deprivation protocols indicate the breaks can provide some amelioration of the usual performance decline and increased fatigue. Heslegrave and Angus (15) demonstrated positive effects associated with 5- to 20-min breaks embedded within 6-h performance blocks in a 54-h sleep deprivation protocol. Beginning

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* Federal Aviation Regulation 121.543 specifies that "... Except as provided in paragraph (b) of this section, each required flight crewmember on flight deck duty must remain at the assigned duty station with seat belt fastened while the aircraft is taking off or landing, and while it is enroute. (b) A required flight crewmember may leave the assigned duty station - (1) If the crewmember's absence is necessary for the performance of duties in connection with the operation of the aircraft; (2) If the crewmember's absence is in connection with physiological needs; or (3) If the crewmember is taking a rest period, and relief is provided. . . . "

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at about 3:00 a.m. on the first morning, after 18 h of prior wakefulness, the subjective sleepiness, mood, and performance of 12 young women benefited from the breaks. Pigeau et al. (21) showed that a 15-min break provided to subjects every 2 h in a 64-h sleep deprivation study resulted in a moderate effect on mood, fatigue, and performance compared with measures taken an hour later after continuous cognitive work. Electrophysiological measures and indexes obtained from a 4-min eyes-closed relaxation period once per hour in a similar 64-h sleep deprivation protocol with 15-min breaks every 2 h also demonstrated a beneficial effect of the breaks (22). In one of the few studies to examine specifically the effects of physiological arousal on wakefulness, Bonnet and Arand (3) demonstrated that verbal and physical activity produced physiological arousal responses and a return to wakefulness in supine subjects performing a Maintenance of Wakefulness test. The higher the heart rate produced by the activity, the more prolonged the wakefulness, although the effects were relatively short-lived (≤3 min).

While these laboratory-based effects are promising, it is uncertain whether they would transfer to a population of older pilots performing flight-related tasks. There have been no controlled studies of the impact of such breaks on a pilot's physiological alertness, subjective alertness, or vigilance performance during nighttime flights. The purpose of the present experiment was to determine the effect of breaks (tightly controlled with respect to timing, duration, and composition) on actual pilots in a high-fidelity simulation of the operational aviation environment. We investigated the effectiveness of brief, regularly scheduled breaks combined with postural change, mild physical activity, and altered social interaction on the ability to maintain vigilance and mitigate the fatigue-inducing effects of nighttime flying.

METHODS

Subjects

The subjects were 28 healthy, male, experienced flight crewmembers (aged 29–62 yr, mean 51.2 ± 8.6) who volunteered for the study and were paid for their participation. They averaged 15,163 total flight hours (2500–28,000) with currency in Boeing 747, 757, 767, and MD 11 aircraft. Of the 28 subjects, 15 regularly flew as captains and 13 as first officers. Subjects were paired randomly with a partner and assigned to either the captain or first officer position based on 747-400 flying experience. The fourteen two-man crews then were assigned randomly to either a treatment or control group.

All subjects were required to follow a structured sleep/wake schedule for three nights just prior to the study—obtaining their typical amount of nighttime sleep between the hours of 10:00 p.m. and 8:00 a.m. On the day of the study they were required to refrain from caffeine use and caffeine-containing medications after 9:00 a.m., as well as alcohol use all day. Subjects were also prohibited from napping on this day. Consequently, subjects were continuously awake for approximately 18–20 h at the start of the experiment.

Measurements

During the 3-d period preceding the study, the timing and duration of the subjects' sleep and wake episodes were monitored for compliance with the protocol by means of an activity monitor worn on the nondominant wrist (AMA-32 , Ambulatory Monitoring, Inc., Ardsley, NY). Subjects also recorded sleep and wake periods during this period with either an electronic (26) or paper sleep/wake diary. On the evening before the study, subjects completed a questionnaire about demographics, physical characteristics, sleep habits and behavior, napping, caffeine use, medication and alcohol use, recent sleep/wake and travel history, flight experience, and fatigue. They also completed a sleep disorders questionnaire (20) and a structured interview on recent sleep history, napping, medication and caffeine use, activity monitor use, and knowledge of their flying partner.

Experiment measures included vigilance performance, subjective sleepiness ratings, electrophysiological measures of drowsiness, and continuous video. Vigilance performance was probed periodically with the Psychomotor Vigilance Task (PVT) delivered via a portable, hand-held, battery-operated device (12). The PVT is a 10-min high-signal-load reaction time task with feedback that has been used to measure sustained attention and reaction time in many operational environments. PVT performance has been shown to be reduced in long-haul pilots flying east-west routes (25). Subjective sleepiness was assessed repeatedly using two measures. The Karolinska Sleepiness Scale (KSS) is a 9-point paper-and-pencil scale requiring less than 30 s to complete. Odd numbers on the scale are defined by sleepiness-related phrases (e.g., 1 = "very alert," 9 = "very sleepy—great effort to keep awake, fighting sleep"). The scale has been validated against electroencephalographic measures of sleepiness (2). Subjective sleepiness also was assessed with an electronic visual analog scale (VAS). The VAS was administered by the PVT device and took less than 15 s to complete. Subjects indicated their level of sleepiness on a 10-point scale in response to the probe "Sleepy?" Electroencephalography (EEG) and electrooculography (EOG) were recorded continuously using a standard montage (C3-A2, C4-A1, O1-A2, O2-A1, ROC, LOC) and an eight channel, portable, battery-operated recorder (Medilog Model 9000 II, Oxford Corp., Largo, FL). Such measurements have been shown to be sensitive indicators of severe sleepiness in awake subjects with eyes open (2). The EEG and EOG data were written to cassette tape for subsequent digitization and analysis. Continuous video monitoring and recording of the face were obtained separately for the captain and first officer from two small infrared cameras (Canon Ci-20R with Canon IR-20 W infrared light module, Canon Inc., Tokyo, Japan), each mounted to the flight deck dashboard at the level of the top of the control wheel. A third infrared camera was mounted above and behind the pilots, providing an overhead view of the flight deck. All three cameras were plainly visible and identified to the pilots and allowed the online monitoring and recording of their activities during the study.

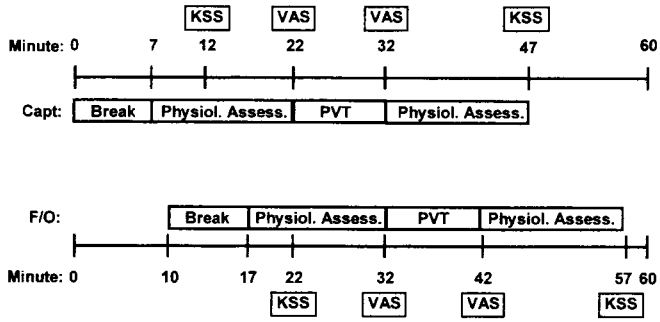

Fig. 1. Schematic of each of the 5 h comprising the cruise portion of the flight for the treatment group showing the relative timing of the 7-min breaks, 15-min electrophysiological assessment periods, 10-min psychomotor vigilance task (PVT) bouts, and visual analog scale (VAS) and Karolinska Sleepiness Scale (KSS) measurements for the captain and first officer. The protocol was identical for the control subjects during the middle (third) hour of cruise. For the first, second, fourth, and fifth hours of cruise, measures were collected at clock times comparable to those for the treatment group.

Procedure

The experimental protocol was reviewed and approved by the NASA Ames Human Research Institutional Review Board. Subjects arrived at the laboratory at approximately 9:00 p.m. after which their activity monitors were checked for compliance with the pre-study sleep/wake protocol. They were briefed on the protocol, provided informed consent, completed the questionnaires and interview, were instrumented for the collection of EEG/EOG, and trained on the performance and subjective measures. Three baseline measurements on the PVT, KSS, and VAS were collected at 2-h intervals beginning 4 h 15 min before the study with the final measures taken while seated on the flight deck.

Beginning at 2:00 a.m., subjects flew an uneventful, 6-h night flight from Seattle, WA (KSEA) to Honolulu, HI (PHNL) in a FAA-certified Level D, Boeing 747-400 flight simulator. The approximate flight plan times included a 20-min segment from take-off to top-of-climb (TOC), a 5-h cruise portion, and a 30-min segment from top-of-descent (TOD) to landing. Heavy use of automation was made during all phases of flight with the autopilot engaged continuously above 5000 ft. Pilots were told to expect no intentional emergencies and the flight plan was constructed to include no events requiring them to take manual control of the aircraft until 5000 ft during descent.

The seven two-man crews in the treatment group received five regularly scheduled 7-min breaks that included mild physical activity combined with social interaction away from the flight deck. The breaks were equally spaced at 1-h intervals during cruise. The experimental protocol for each hour of the flight during cruise is shown in **Fig. 1**. Subjects were notified via their headsets when to take a break by an experimenter acting as air traffic controller. The captain took his first break immediately on reaching TOC, getting out of the seat, exiting the flight deck, and descending the stairs of the simulator. The first officer remained on the flight deck to continue flight operations. The captain was accompanied by an experimenter to a dimly lit break room where light snack food and a lavatory were available. He was prohibited from heavy exercise during this period but was required to remain standing and was engaged in conversation by the experimenter on topics unrelated to the experiment. Just prior to the end of the 7-min period, the captain was escorted back to the simulator. After allowing 3 min for the captain to become re-oriented, the first officer took his first break (10 min after TOC), also returning 7 min later. This schedule was repeated five times with the breaks spaced at 60-min intervals throughout the cruise portion of the flight.

The seven crews in the control group received only a single, mid-flight, 7-min break. This break was timed to occur at the same point as the middle of the five breaks taken by the treatment group and was identical in every way. In order to avoid expectancy effects, all subjects were kept unaware as to the existence of treatment and control groups. They were also unaware as to the number and timing of the breaks, being informed in advance only that they would receive one or more 7-min breaks at an unspecified time(s) during cruise.

EEG/EOG and video of the face were collected continuously. For the treatment group, the KSS was administered 5 and 40 min post-break, resulting in 10 administrations during the flight. The control group completed the KSS 5 and 40 min after the end of their sole break and at all other clock times corresponding to when the treatment group completed the task, also for a total of 10 administrations. The PVT was performed 15 min post-break for the treatment group, resulting in five in-flight administrations. Since the start of the breaks was separated by 10 min for the captain and first officer, and the PVTs were 10 min long, they were completed back-to-back by captain and first officer in their flight deck seat. Control group subjects performed the PVT at comparable times (i.e., 15 min after their sole break and 15 min after the time when other breaks would have ended had they received them). The relative timing of the PVTs for control captains and first officers was the same as for the treatment group. The VAS was administered by the PVT device before and after the PVT at 15 and 25 min post-break for the treatment subjects and at comparable times for the control subjects. Both groups completed a final PVT, KSS, and two VASs in their seat on the flight deck as soon as practicable after landing. No interaction was allowed between subjects during any of the performance tests or subjective assessments. After exiting the simulator at the end of the experiment, subjects completed a debrief questionnaire and interview. Following de-instrumentation they were driven to their hotel for recovery sleep.

RESULTS

Statistical Analyses

Statistical analyses were conducted on variables extracted from the PVT, KSS, VAS, and electrophysiological data using a two-way, mixed-model analysis of variance (ANOVA) with Group as the between-subjects variable with two levels (treatment group, n = 14 vs.

control group, n = 14)[†]. Time was the repeated factor with four levels associated with measures collected after the first, second, fourth, and fifth breaks received by the treatment group (and corresponding times for the control group)[‡]. Measures associated with the third break were eliminated from the omnibus ANOVA because this break was received by both groups. F-ratio significance levels were corrected for sphericity by Greenhouse-Geisser epsilon. Significant interactions were further analyzed by one-way ANOVAs to test for simple effects. Independent and paired *t*-tests were used to compare outcomes at discrete time points, with corrections to the degrees of freedom for independent *t*-tests applied in cases of unequal variances. Before being submitted to ANOVA, an arcsine transformation was applied to percentage values to correct for deviations from normality (16).

Magnitude and Quality of the Effect

Electrophysiological data: All electrophysiological data were scored visually by a registered polysomnographic sleep technologist naïve to the specific conditions of the experiment including clock times when the data were collected, the existence of breaks and subject groups, the experimental hypotheses, and all experimental manipulations. He was aware only that the data were collected from awake and seated subjects in a flight simulator. After data digitization, he performed a visual analysis of printed records, annotating them for the following parameters: 1) *Alpha activity*: Alpha-band activity (8–13 Hz) in the EEG of 2 s or longer in duration was annotated on the records. Alpha activity is associated with a state of relaxed wakefulness with eyes closed but can also be seen in excessively sleepy individuals with eyes open. In such cases, alpha is attenuated with eyes closed by the intrusion of stage 1 sleep (4). 2) *Slow eye movements*: All slow eye movements (SEMs) in the EOG channels of 4 s or longer in duration were noted. Involuntary, slow rolling eye movements are characteristic of extreme sleepiness and frequently precede (from seconds to minutes) the transition from wakefulness to stage 1 sleep (4). The SEM measure also included slow eye closures shown to be associated with vigilance lapses (10). 3) *Theta activity*: Evidence of theta-band activity (3–7 Hz at 50–75 μV) in the EEG that was 2 s or longer in duration was annotated. Generally, theta is the EEG activity band with the highest relative amplitude during stage 1 sleep (4). 4) *Sleep*: Any duration of stage 2 or 3 sleep equal to or greater than 2 s was indicated on the records. Rechtschaffen and Kales criteria (23) were followed with the exception that epoch scoring was not used. The intent was to detect all instances of sleep, no matter how brief, given the relevance of even microsleeps in operational environments such as the flight deck. All instances of these four parameters were entered into a computer database and statistically analyzed for different experiment time segments. Proportions were used in all analyses to correct for different segment lengths caused by slight variations in the timing of the protocol segments.

In order to detect an immediate effect of the break and assess its magnitude, data were analyzed for the 15-min post-break periods from the end of the break to the start of the PVT for each of the four electrophysiological measures (see Fig. 1). Alpha activity failed to show a consistent pattern. SEMs, theta activity, stage 2/3 sleep, and the combination of theta and sleep are plotted in **Fig. 2**. Results from the ANOVA for SEMs showed a significant Group × Time interaction ($p < 0.05$). The treatment group showed a significant increase ($p < 0.001$) in the percentage of SEMs across successive post-break periods, beginning at less than 1% of the 15-min period at 2:40 a.m. to a maximum of about 6% by the last period at 6:40 a.m. (Fig. 2a). However, the control group's values were much higher, ranging from about 3% at 2:40 a.m. to a peak of 15% at 5:40 a.m., falling only slightly to 13% at 6:40 a.m. This pattern also represented a significant increase across time ($p < 0.001$). The exception to this trend is at 4:40 a.m. following the control group's only break. At that time, the control group value (~4%) was reduced to one nearly identical to that of the treatment group. The control group exhibited a significantly higher percentage of SEMs than the treatment group during post-break periods in the latter half of the night at 5:40 a.m. ($p < 0.001$) and 6:40 a.m. ($p = 0.01$).

A similar pattern can be seen for theta activity (Fig. 2b) with a significant Group × Time interaction ($p < 0.01$). However, the treatment group exhibited no significant increase in theta over the course of the night while the control group showed a significant increase ($p < 0.001$). Again, there were statistically significant differences between the groups in the latter half of the night at 5:40 a.m. and 6:40 a.m. (both $p < 0.01$), with the controls showing greater evidence of sleepiness. For 11–12% of these time periods, the control subjects exhibited theta activity associated with stage 1 sleep compared with ≤ 2% for the treatment subjects. Furthermore, theta was detected in 12 of the 14 controls at these 2 times, but only 3 (at 5:40 a.m.) or 7 (at 6:40 a.m.) of the 13 treatment subjects.

Fig. 2c shows the amount of unequivocal sleep in the cockpit seat during these same post-break periods. There was a non-significant trend toward a Group × Time interaction ($p = 0.08$). The groups differed in the amounts of sleep occurring after the last break at 6:40 a.m. ($p < 0.05$) and showed a trend toward a difference at 5:40 a.m. ($p = 0.06$). Only 1 treatment subject slept in the cockpit during any of the post-break periods, while 9 of the 14 control subjects (64%) slept during the fourth or fifth post-break periods in the latter half of the night.

Combining theta activity and stage 2/3 sleep reveals the amount of post-break time spent either clearly asleep or on the verge of sleep in a transitional state (Fig. 2d). The ANOVA shows a significant Group × Time interaction ($p < 0.01$). Across time, the control

[†]All data sets were complete with the exception of lost EEG/EOG data for one treatment subject due to equipment malfunction.

[‡]All subsequent references to "post-break periods" refer to the five such periods for the treatment group, the sole post-break period for the control group, and other time periods for the control group that exactly correspond to post-break periods 1, 2, 4, and 5 for the treatment subjects.

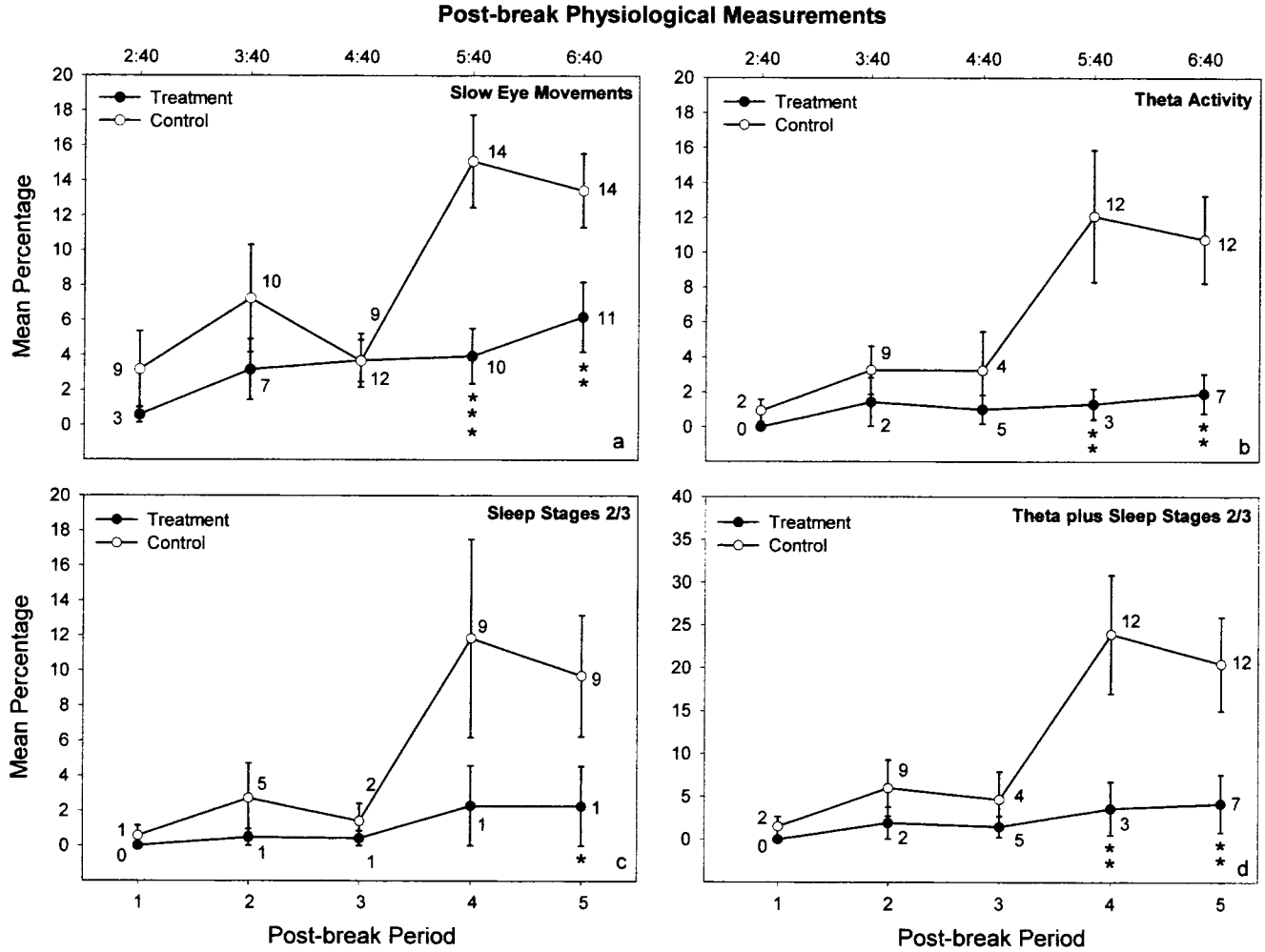

Fig. 2. Electrophysiological measures obtained during the five 15-min post-break periods and at corresponding times for the control group. Mean mid-point post-break time is indicated on the top axis. Panel (a) shows the mean percentage (±1 s.e.m.) of post-break period time with slow eye movements, each ≥ 4 s in duration. Theta activity (≥ 2 s in duration), stage 2 or 3 sleep (≥ 2 s in duration), and the combination of theta activity and sleep are shown in panels (b-d), respectively. The numbers next to each data point represent the number of subjects with data values greater than zero. *p ≤ 0.05, **p ≤ 0.01, ***p ≤ 0.001.

group displayed a significant increase in the proportion of time in theta and stage 2/3 sleep ($p < 0.001$) while the treatment group did not. The amount of time displaying theta or sleeping by the treatment group never exceeded 4% of the post-break period while reaching 24% for the control group at 5:40 a.m. The differences between the groups at 5:40 a.m and 6:40 a.m. were statistically significant (both $p < 0.01$). Of the control subjects, 12 (86%) showed evidence of sleep or extreme sleepiness in the latter half of the night compared with a maximum of 7 of the 13 treatment subjects (54%).

In order to determine further whether the mean percentages in Fig. 2 were disproportionately affected by only a few subjects, histograms of these data at post-break periods in the latter half of the night are provided in **Fig. 3**. It is clear from the figure that, for post-break periods 4 and 5, where the significant differences between groups occur, the control group has a broader distribution with more subjects showing higher percentages of SEMs, theta, and sleep. Furthermore, for every physiological measure obtained during every post-break recording period but one, the maximum percentage of SEMs, theta activity, or sleep was exhibited by a control subject(s). (The sole exception is for SEMs after the third break received by both groups.) During the fourth post-break period at 5:40 a.m., two of the controls produced theta-band activity for 40% of the time (Fig. 3b) and another spent 68% of the time asleep (Fig. 3c).

Subjective data: Independent *t*-tests comparing mean KSS values for treatment and control groups on the three trials obtained before take-off revealed no differences between the groups prior to the experiment. An ANOVA on the in-flight KSS measures 5 min post-break revealed a significant main effect with the control group reporting greater sleepiness than the treatment group ($p < 0.001$). Both groups started the experiment at 1:55 a.m. "neither sleepy nor alert" and showed a circadian-mediated increase in sleepiness over the course of the night flight (**Fig. 4a**), resulting in a main effect of Time ($p < 0.001$). By the latter half of the night at 5:35 a.m. and 6:35 a.m., the controls reported sleepiness levels very close to the top end of the scale ("very sleepy —great effort to keep awake, fighting sleep"). The mean level for treatment subjects did not exceed "sleepy—but no effort to keep awake" at 6:35 a.m. The

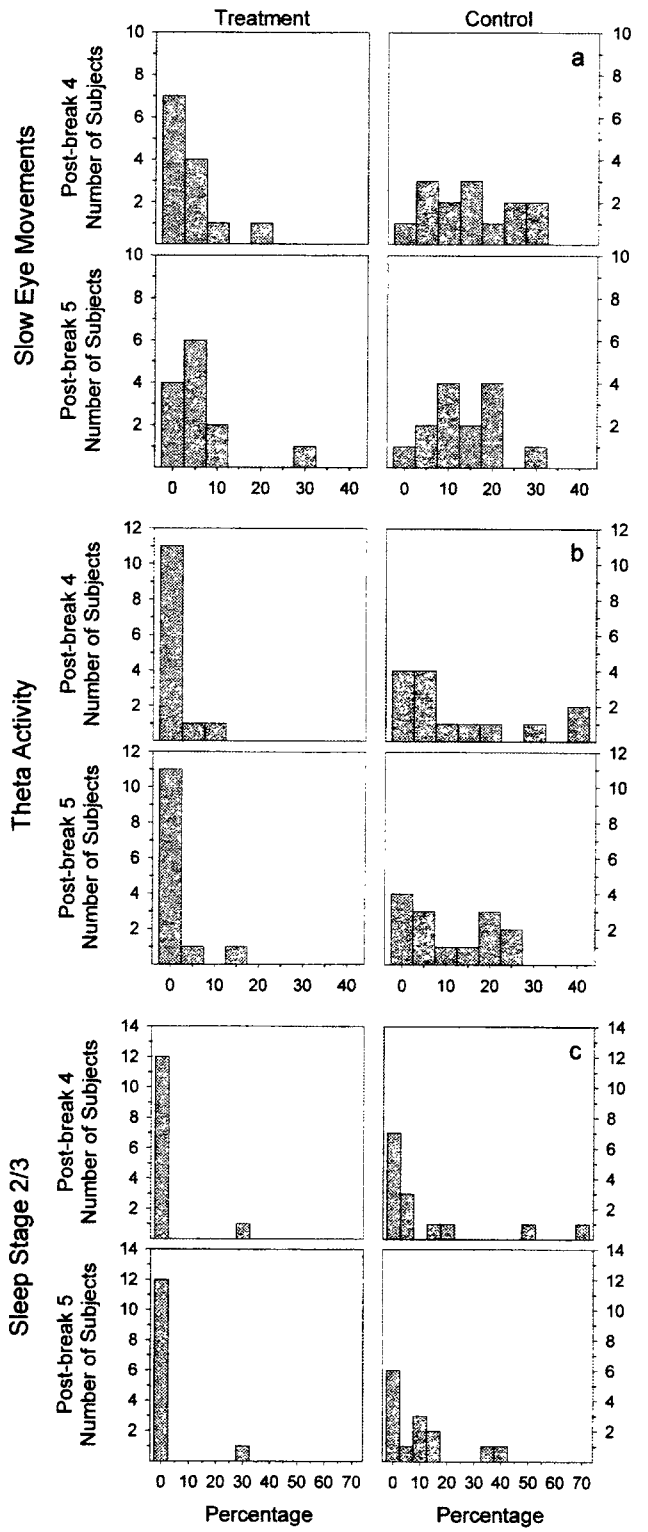

Fig. 3. Histograms of the number of subjects exhibiting SEMs (panel a), theta-band activity (panel b), and sleep (panel c) during the fourth and fifth post-break periods, binned by percentage of time displaying that activity.

only break received by the controls appeared to temporarily prevent any further decline in subjective sleepiness 5 min post-break. Comparisons at specific times indicate that control subjects reported being significantly more sleepy than treatment subjects 5 min after the second break at 3:35 a.m. ($p < 0.05$), the fourth break at 5:35 a.m. ($p < 0.001$), and the fifth break at 6:35 a.m. ($p < 0.001$). The latter two measures are near the time of the circadian trough associated with maximum daily sleepiness levels. There were no differences between the groups at 4:35 a.m., 5 min after the break received by both. The difference in reported sleepiness between the groups remained present after the end of the flight at 7:55 a.m. ($p < 0.05$).

An ANOVA on the in-flight KSS measures collected 40 min post-break showed only a main effect of Time ($p < 0.001$), reflecting the same circadian-mediated increase in sleepiness over the course of the flight as the data collected 5 min post-break (Fig. 4b). There was no statistically significant difference in overall sleepiness between groups. Thus, while the breaks resulted in significantly less reported sleepiness by treatment subjects 5 min after its end for all breaks except the first, any subjective alertness improvement dissipated by 40 min post-break.

The VAS provided additional information on the time course of subjective sleepiness since it was administered 15 and 25 min post-break (**Fig. 5**). Independent *t*-tests revealed no differences on the VAS between groups prior to the flight. The two-way ANOVA on the in-flight VAS measures taken 15 min post-break revealed a significant main effect of Group ($p < 0.05$), with a greater level of overall sleepiness in the control subjects. There was also a significant main effect of Time ($p < 0.001$), indicating an increase in sleepiness throughout the night for both groups. However, there were differences. The control group showed a large increase in subjective sleepiness, mitigated slightly by the one break in the middle of cruise, with levels approaching the top end of the scale in the latter half of the flight (Fig. 5a). The treatment group showed a nonsignificant drop in sleepiness after the first break. Sleepiness levels remained below those of the control group for the remainder of the flight, despite also increasing in a circadian-mediated fashion. The treatment group showed a strong trend toward less sleepiness than the control group 15 min after the first break ($p = 0.06$), with differences between groups reaching statistical significance after the fourth ($p = 0.01$) and fifth ($p < 0.01$) breaks at 5:45 a.m. and 6:45 a.m., respectively. There was a drop in reported sleepiness for both groups after the flight at 7:45 a.m.

The treatment and control groups also differed in subjective sleepiness on the VAS 25 min after the in-flight breaks. The pattern of sleepiness (Fig. 5b) was similar to that for the 15-min post-break measures. Again, there were significant main effects of Group ($p < 0.05$) and Time ($p < 0.001$) with the controls reporting greater sleepiness while both groups showed increases in sleepiness during the flight. The control group reported significantly greater sleepiness than the treatment group 25 min after the fourth ($p < 0.01$) and fifth ($p < 0.01$) breaks at 5:55 a.m. and 6:55 a.m., respectively. The groups remained significantly different ($p < 0.05$) after the flight at 7:55 a.m.

In sum, the two subjective sleepiness measures indicated that the breaks resulted in relative reductions in

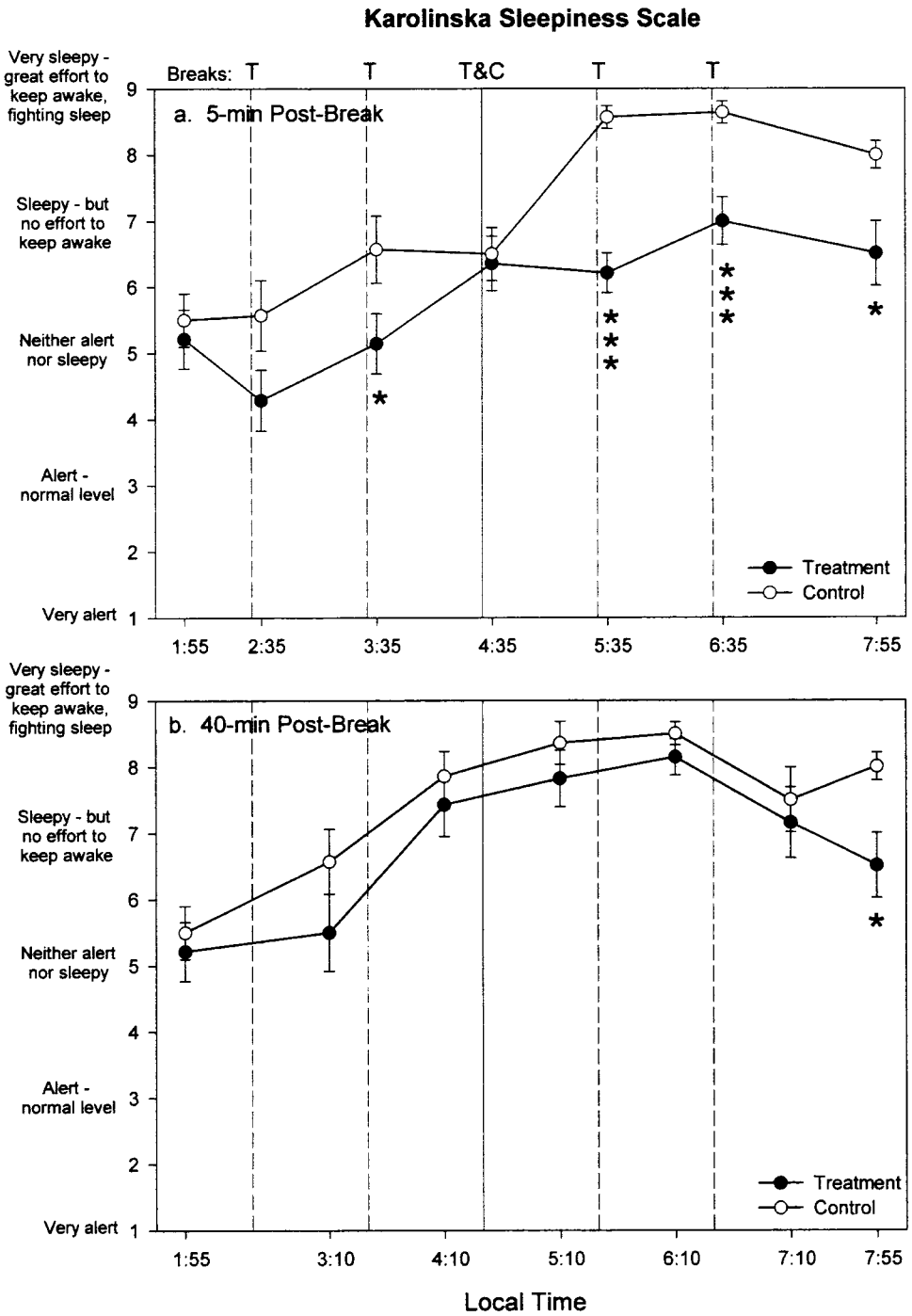

Fig. 4. Mean (±1 s.e.m.) Karolinska Sleepiness Scale (KSS) values obtained at mean scheduled times pre-flight (1:55 a.m.), in-flight (2:35–7:10 a.m.) and post-flight (7:55 a.m.) for the treatment and control groups. The timing of the five breaks is indicated by the dashed lines (T: break received by treatment group only) and solid line (T&C: break received by both groups). The KSS was administered at 5 min (panel a) and 40 min (panel b) post-break for the treatment group and at corresponding times for the control group. Other features are the same as in Fig. 2.

subjective sleepiness when it was reported 5, 15, and 25 min after the hourly breaks. While the trend toward less sleepiness for the treatment subjects, relative to the controls, started right after the first break at about 2:30 a.m., the largest differences were seen in the second half of the flight (~5:30–7:00 a.m.). The reported improvements dissipated by 40 min post-break.

Performance data: Consistent with previous studies on changes in attention-based performance (11,12,25), multiple aspects of PVT performance were assessed. 1) *Lapsing:* The number of performance lapses (RTs > 500 ms) per 10-min PVT trial was tallied. Lapses reflect the most serious loss of performance capability in fatigued subjects because they represent a failure to respond (or respond in a timely manner) to a monitored signal. Total lapse values per trial were transformed using $[(x)^{0.5} + (x + 1)^{0.5}]$ to reduce heterogeneity of variance from large inter-subject variability (7). Analyses were performed on transformed values while the graph of PVT lapses displays actual, untransformed values. The total duration of all response times > 500 ms (lapse dwell time) was also calculated, in order to take into account very long response latencies. 2) *Cognitive slowing*: Shifts in lapse duration were calculated as the average of 1/RT for the 10% slowest RTs (8). This metric reflects vigilance response slowing. We also assessed

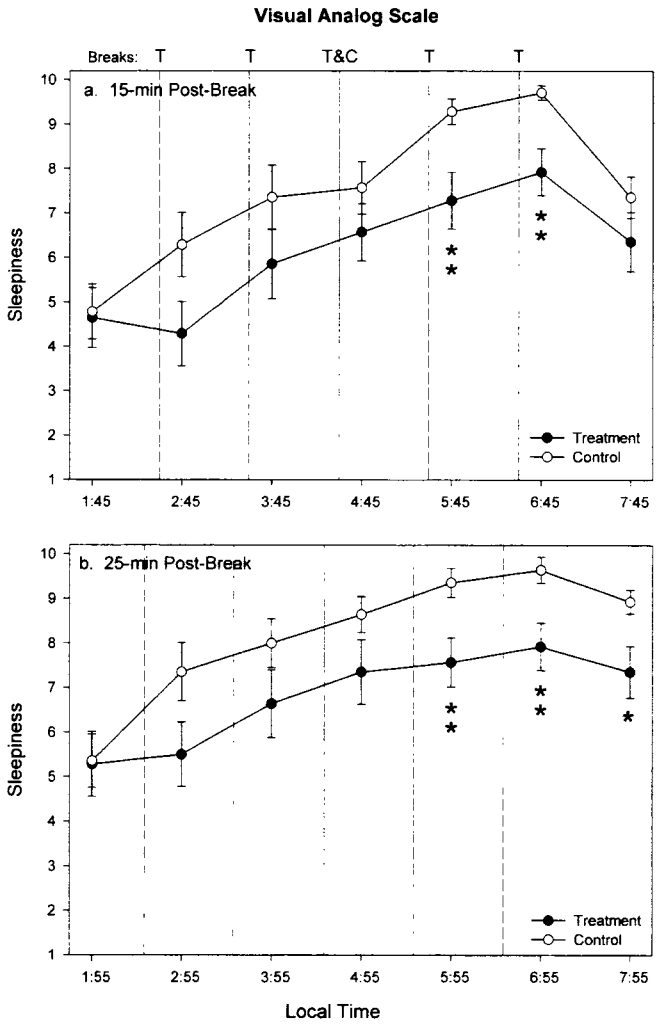

Fig. 5. Mean (±1 s.e.m.) Visual Analog Scale (VAS) values obtained at mean scheduled times pre-flight (1:45 a.m., 1:55 a.m.), in-flight (2:45–6:55 a.m.) and post-flight (7:45 a.m., 7:55 a.m.) for the treatment and control groups. The VAS was administered at 15 min (panel a) and 25 min (panel b) post-break for the treatment group and at corresponding times for the control group. Other features are the same as in Fig. 4.

the presence of cognitive slowing, as reflected by a change in the distribution of reaction times, by analyzing the median reaction time for the two groups. 3) *Optimum response times*: PVT optimum response times were calculated as the average of the 10% fastest RTs per trial (7). This metric reflects loss of the very best performance a subject is capable of producing. 4) *Fatigability*: The vigilance decrement function (or the extent to which subjects maintained performance across time on task) was assessed as the slope derived from a least-squares regression equation fit to the 1-min averages across each 10-min PVT trial (13,17). This metric reflects the ability of the subject to sustain a consistent level of performance during a task interval. 5) *False responses:* False responses (anticipatory responses < 100 ms) were tallied (7). This metric reflects a decrease in response inhibition with a corresponding increase in errors of commission.

Lapse frequency and median reaction time (**Fig. 6**) are representative of all PVT measures in showing a circadian-mediated decrease in performance throughout the night. An increase in performance variability, characteristic of fatigued subjects, is reflected by the much larger error bars associated with the in-flight measures, compared with pre- and post-flight. All PVT measures were consistent in showing no pre-flight between-group differences. For all PVT measures obtained between 15 and 25 min post-break during the flight, ANOVAs showed significant effects of Time. However, the same analyses failed to detect any statistically significant differences between the groups on any of the vigilance measures. For all measures, poorest performance occurred in the latter half of the night at 5:50 a.m. and 6:50 a.m. The post-experiment PVT at 7:50 a.m. showed a mean lapse frequency and median reaction times that returned most of the way to pre-flight baseline values.

Duration and Time-Course of the Effect

The foregoing analyses revealed the break had a beneficial effect on physiological alertness during the 15-min period immediately following, until the start of the

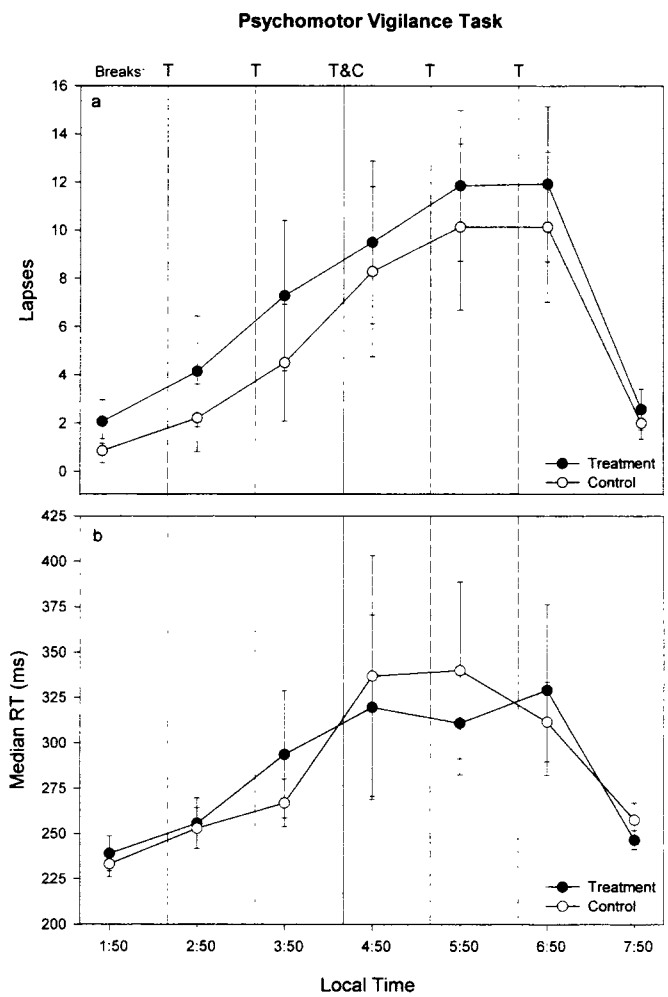

Fig. 6. Mean (±1 s.e.m.) Psychomotor Vigilance Task (PVT) measures obtained at mean scheduled times pre-flight (1:50 a.m.), in-flight (2:50–6:50 a.m.) and post-flight (7:50 a.m.) for the treatment and control groups. The PVT was administered from 15–25 min post-break for the treatment group (corresponding times for the control group). Other features are the same as in Fig. 4.

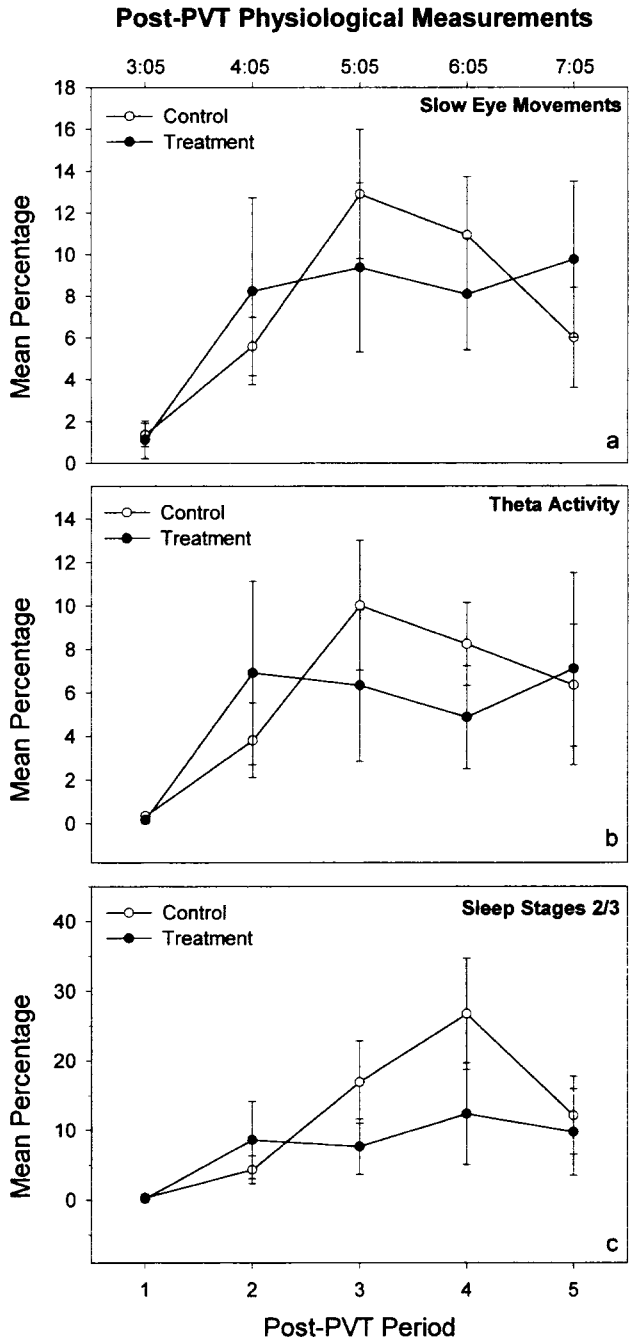

Fig. 7. Electrophysiological measures obtained during the five 15-min post-PVT periods and at corresponding times for the control group. Mean mid-point post-PVT time is indicated on the top axis.

PVT. There was also a subjective feeling of improved alertness 25 min post-break, at the end of the PVT. However, any feelings of subjective improvement were absent by 40 min post-break. In order to determine more precisely the duration of the effect, electrophysiological data from 25–40 min post-break were analyzed.

Electrophysiological data 25–40 min post-break: **Fig. 7** compares the control and treatment groups on the post-PVT physiological measures. SEMs ($p < 0.001$), theta ($p < 0.001$), and sleep ($p < 0.01$) all showed a main effect of Time, with sleepiness increasing through the night and decreasing toward landing and the experiment end. There was no main effect of Group or Group × Time interaction. Despite a trend for the control group to show evidence of increased physiological sleepiness relative to the treatment group 25–40 min after the third and fourth breaks at 5:05 a.m. and 6:05 a.m., the groups did not differ statistically at any of these discrete time periods.

Debrief Interview

After completion of the study, subjects were formally debriefed, answering questions about fatigue levels during the flight, effectiveness of the experimental treatment, and other aspects of the protocol. The pattern of responses was very similar for the two groups. The protocol was successful in creating fatigue as evidenced by all 28 subjects reporting they felt fatigued at some point during the flight, many saying they were "very fatigued." Most reported the greatest fatigue was experienced in the middle to latter portions of the flight. Compared with a normal duty flight, all 28 subjects responded that they felt more fatigued during this simulated flight. Of the 28 subjects, 9 from the treatment group and 9 from the control group considered the flight harder than normal duty flight, with 10 treatment subjects and 12 control subjects reporting decreased concentration levels. The majority of the subjects (25 of 28) thought the interactions with the other crew member aided their alertness levels; 23 of the subjects thought interactions with research staff had the same beneficial effect. All but one treatment subject and one control believed the breaks improved alertness and 75% considered the snacks to have a positive effect. Only 2 of the 28 subjects felt their actions were influenced by knowing they were being monitored on video. Finally, none of the subjects correctly identified the true purpose of the experiment.

DISCUSSION

The brief hourly breaks resulted in significant reductions in both physiological sleepiness (as assessed by SEMs and theta-band activity) and unintended sleep for at least 15-min post-break (see Figs. 2 and 3). Two different measures consistently revealed a beneficial effect of the breaks on self-reported sleepiness for up to 25 min post-break (see Figs. 4a, 5a and b). By 40 min post-break, any feelings of improved alertness had dissipated (Fig. 4b). These subjective and physiological effects were most pronounced in the latter half of the night, near the time of the circadian trough in body temperature and the peak in the daily sleepiness rhythm. Thus, the breaks were most effective at that time of the 24-h day when needed most.

One of the most surprising findings in this study was the extent of the sleepiness engendered by the protocol. The 18–20 h of wakefulness before the start of the experiment, combined with the uneventful flight and heavy use of automation, evidently combine to create a sleep-conducive environment. Despite being wired for electrophysiological recording and knowingly monitored by video throughout the flight, most controls and a few treatment subjects fell asleep while flying the

simulator. While sleep in the cockpit seat is admitted frequently in surveys (5,24), reported anecdotally, and observed in at least one field study (25), sleep episodes in the present study were often long in addition to being frequent. In several instances, sleep episodes would have been even longer had not the air traffic controller needed to wake the pilot in order for him to perform a performance measure on schedule. In this environment, the data of Fig. 2 are compelling in demonstrating the utility of the breaks in keeping sleep and other physiological indicators of sleepiness to a minimum for at least 15 min following the break. Whether the physiological benefit associated with the break exceeds 15 min cannot be determined from the present protocol due to the requirement of performing the PVT 15 min post-break. By the time the PVT finished 25 min after the break, there was no further physiological evidence of the break's benefit (Fig. 7). It is possible the performance of the PVT itself served as an arousal stimulus for the pilots.

The PVT did not indicate a beneficial effect of the breaks on vigilance performance. It did show a strong circadian pattern with expected performance deterioration occurring in the latter part of the flight (5:50–6:50 a.m.) due to elevated sleep drive and circadian time. This was followed by a strong improvement at 7:50 a.m. This earlier-than-expected performance improvement may be related to greater task demand associated with the landing of the airplane that just occurred, increased compensatory effort on reaching the end of the study, and/or this older population of subjects being somewhat circadian phase-advanced. The general failure of the PVT to detect any effect of the break may be due to one or more of several possible reasons. First, the PVT may not be sensitive enough to detect an effect of the break. Or it might have been possible to detect an effect at points in time other than the fixed time points relative to the breaks. While the breaks evidently allowed subjects to resist physiological sleepiness under a heavy challenge, perhaps they were not able to prevent a performance decline under a performance challenge. They may result in increased arousal that mitigates against subjective sleepiness, physiological drowsiness, and frank sleep onsets that would otherwise occur, without being strong enough to arrest the decline in vigilance performance. For one or more of these reasons, the breaks affected physiology and subjective sleepiness without impacting PVT performance. Interestingly, naps provided to pilots on the flight deck showed no effect on subjective sleepiness but did have a significant beneficial effect on PVT performance and physiology (25).

The breaks can be considered to have several distinct aspects: a change in workload and nature of the activity, a postural change accompanied by a slight increase in physical activity level, a change in the nature and amount of social interaction, and the opportunity to eat. The present protocol cannot distinguish the relative effectiveness of these factors in maintaining alertness in sleepy subjects. However, there is recent evidence that social interaction and posture can play a role in maintaining alertness, particularly around the time of the circadian trough (6). During a period of sleep deprivation, moderate exercise or a brief bout taken before testing can result in no additional decrement in performance (1,28) or even a beneficial effect (19,27,29). In a recent study, 10 min of exercise every 2 h during 40 h of continuous wakefulness showed a beneficial effect for about 30 min, with some indication of increased sleepiness about an hour after the bout (18). Whether the breaks would be as effective if spaced less frequently is also impossible to answer from the present protocol. More frequent breaks, while possibly more effective, may not be operationally feasible. However, regardless of which aspect of the breaks mediated the reduction in sleepiness, the inextricably entwined components resulted in a moderately effective countermeasure when applied briefly and hourly.

Despite the reductions in both physiological and subjective sleepiness, the data should not be interpreted as implying that breaks during a period of extended wakefulness are a reasonable substitute for adequate sleep in advance of, or during, the period of wakefulness (e.g., "preventive" or "operational" naps). Napping in anticipation of a prolonged period of wakefulness can have a beneficial effect hours later (11). A 40-min nap opportunity while on the flight deck is both more effective and long-lasting than a break, showing a benefit in vigilance performance as well as physiological sleepiness (25). Nevertheless, the breaks in the present study clearly resulted in a physiological improvement for at least 15 min. The fact that only subjective measures revealed a difference between groups 25-min post-break may be evidence of a "masking" effect of the break on underlying sleepiness that remains after the physiological benefit wanes.

A word of caution is in order when considering the use of breaks on the flight deck. As employed in the present study, breaks necessarily involved the removal of one pilot from the flight deck. On a two-person flight deck, such a change would cause an immediate cessation of social interaction for the remaining pilot. Given the potential importance of social interaction in maintaining the alertness of sleepy subjects, the break, while beneficial to the crew member receiving it, could put the remaining crew member at an increased risk of sleepiness, performance impairment, and uncontrolled sleep. The same challenges arise when considering the implementation of napping on the flight deck. One approach would be to bring a cabin crew member onto the flight deck during the break or nap, or have him or her make frequent visits, to interact with the flying pilot. A more long-term solution is the development of objective, online, and automated fatigue-monitoring systems that can alert the flying pilot as to when he or she is showing signs of significant drowsiness. This could represent a significant benefit for cargo operations where, in most cases, an additional crewmember is not available. Such a system could also prompt the pilot to take corrective action in the form of a countermeasure (e.g., nap, break, caffeine, increased interaction). Such technologies are under development (9,10) but it remains unknown whether they will find their

way onto the flight deck as well as into other transportation environments.

In conclusion, brief (7-min) hourly breaks were shown to be effective in reducing nighttime physiological and subjective sleepiness for at least 15 min post-break and may have continued to mask sleepiness for up to 25 min. While not currently sanctioned by the FAA for commercial pilots, such breaks, employed as part of a broader alertness management approach, show significant potential usefulness as an in-flight fatigue countermeasure.

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