Circadian Adaptation of Aircrew to Transmeridian Flight

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Background: Most research investigating the rate of circadian adaptation to transmeridian flight has focused on single, acute time zone transitions. Often, however, aircrew experience compound time zone transitions, the physiological effects of which are not well understood. The primary aim of the current study was to investigate the circadian adaptation of a Royal Australian Air Force (RAAF) aircrew to several small time zone transitions using salivary melatonin onset as the marker of circadian phase. Methods: Fifteen members of an RAAF aircrew collected saliva samples, sleep/wake records, and subjective alertness ratings during a 13-d surveillance patrol around the southwest Pacific Ocean. Results: During the first 6 d of the surveillance patrol, the aircrew traveled 3.5 time zones east and melatonin onset advanced by 3.8 h. During the next 6 d the aircrew traveled 2 time zones west, but melatonin onset did not shift. Night-time sleep duration was shorter prior to workdays (6.4 h) than prior to rest days (8.4 h). Subjective alertness was not significantly affected by either the duration of night-time sleep prior to work, or the duration of the flight. Conclusions: The melatonin onset results indicate that participants’ body clocks adapted well to several small time zone transitions when initially traveling eastward, but did not adapt to a similar pattern of time zone transitions when subsequently traveling westward. This finding is contrary to expectations based on studies of single acute time zone transitions which indicate that adaptation to westward flight is more rapid than adaptation to eastward flight.

Keyword: shiftwork, transmeridian flight, circadian rhythms, salivary melatonin, sleep, subjective alertness.

SIMILAR TO SHIFTWORKERS in other industries, aircrew experience work-related fatigue because they often work irregular schedules that involve long work periods, early start times, and night work. For aircrew, transmeridian flight (i.e., flight across one or more time zones) is an additional source of fatigue that is typically manifest in jet lag symptoms that include difficulty initiating or maintaining sleep at night, daytime sleepiness, decreased alertness, and impaired performance. In extreme cases, the fatigue-induced impairment associated with transmeridian flight may be so severe as to contribute to an incident or accident. Indeed, the accident rate for long-haul commercial sectors (i.e., those likely to involve transmeridian flight) is almost three times that for short- and medium-haul sectors (10).

Aircrew experience jet lag symptoms due to the fatigue and sleep loss associated with long flights and the disruption to circadian rhythms associated with crossing time zones. After transmeridian flight, the rate of resynchronization of the circadian timing system with local zeitgebers depends on the number of time zones crossed and the direction of flight. Typically, the rate of resynchronization is faster if more time zones are crossed and if flight is in a westward direction, irrespective of the relative direction of flight (i.e., outbound or return), or whether flight takes place during the day or night (2,13,15,26).

In laboratory simulations and field studies of transmeridian flight, researchers have typically assessed biological adaptation by monitoring rhythms of core body temperature. However, the endogenous rhythm of body temperature is masked by the sleep/wake and activity/rest cycles (24). Consequently, the onset of endogenous melatonin production, determined by radioimmunoassay of blood, saliva, or urine, has been proposed as an alternative marker of circadian phase that is not masked by physical activity or social cues (19,22).

Most research investigating the physiological effects of transmeridian flight on aircrew has considered the rate of adaptation of the circadian timing system to single, acute time zone transitions. In many flight operations, however, aircrew experience compound time zone transitions rather than a single shift. The physiological effects of such patterns of time zone transitions are not well understood. Consequently, the aim of the current study was to (i) assess the biological adaptation of a Royal Australian Air Force (RAAF) aircrew to several small time zone transitions during a 13-d surveillance patrol, using salivary melatonin onset as the circadian phase marker, and (ii) determine the effect of the aircrew’s work schedule on their sleep/wake patterns and subjective alertness levels. It was hypothesized that outbound eastward flight would result in a phase advance of the circadian timing system, manifest in relatively earlier melatonin onset, and that return

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westward flight would result in a phase delay of the circadian timing system, manifest in relatively later melatonin onset. In addition, it was hypothesized that the work schedule would interfere with sleep and im-

pair alertness.

METHODS

Participants

Participants were 15 members of an RAAF Orion P-3 aircrew (all male) who gave informed consent to par-
ticipate in the study as volunteers. The study was ap-
proved by the University of South Australia Human
Research Ethics Committee. Participants were aged be-
tween 24 and 42 yr, with a mean (±SD) age of 30.4 ± 5.3
yr. Nine participants lived with a partner, and six of
these had at least one child under twelve years of age.
The other six participants did not live with a partner
and had no young children. On average, participants
had worked in the RAAF for 10.1 ± 5.3 yr and had been
flying transmeridian missions for 6.4 ± 4.2 yr. Partici-
pants did not receive any additional payment for par-
ticipating in the study above their usual RAAF salary.

Work Schedule

Participants performed a 13-d surveillance patrol
throughout the southwest Pacific Ocean during the
Australian winter. During the first 6 d, participants
traveled 3.5 time zones east, from Edinburgh RAAF
Base, South Australia (34°42′ S 138°37′ E) to Apia, West-
ern Samoa (13°48′ S 171°49′ W). During the last 7 d they
traveled 3.5 time zones west, returning to Edinburgh.

During a typical workday, participants woke before
sunrise, traveled together from their hotel to the local
airport, prepared the aircraft for a post-sunrise take off,
and flew throughout the day. When the day’s task was
completed, the aircrew landed in a new location before
sunrise, commuted together to a local hotel and assem-
bled for a debriefing session, ate dinner and socialized,
then went to bed. The mean shift duration (± SD) was
9.5 ± 1.5 h, of which 6.3 ± 1.3 h were spent flying.

The fifth, ninth, and twelfth days of the surveillance
patrol were rest days. On rest days, participants had
complete discretion as to how they spent their time.
Some participants chose to sleep in, while others went
sightseeing or swimming or otherwise acted like tour-
ists. Those who rose from bed earlier on days off typi-
cally went to bed earlier the night before, but a few had
both late nights and early mornings.

Procedures

Circadian phase shifts were determined by monitor-
ing the daily timing of salivary melatonin onset. Saliva
samples were collected in plain salivettes (Sarstedt,
Numbrecht, Germany) on a baseline day, which was 2 d
prior to the surveillance patrol, and on each day of the
surveillance patrol (except for the last day—no samples
were collected on return to home base). Samples were
collected at hourly intervals in the evening from 18:00
or 19:00 h (local time) until sleep onset. Samples were
kept in ice during the surveillance patrol, and then
stored at −20°C until they were assayed 2–3 mo later.

Saliva samples were analyzed for the hormone mel-
tonin by a direct radioimmunoassay (RIA) with re-
agents from kits produced by Bühlmann Laboratories
AG (Allschwil, Switzerland) and using the method de-
scribed by Vouslitsios et al. (31). There were occasions
when a participant was not able, or forgot, to collect a
sample. If a sample was missed such that melatonin
onset could not be determined, that data point was
excluded from the analyses.

Measures of sleep/wake status were determined for
a baseline day, which was 2 d prior to the patrol, and
for each day of the patrol. Each participant kept a sleep
diary and wore an activity monitor on their wrist
(Gaehwiler Electronic, Hombrechtikon, Switzerland)
for the duration of the study.

Participants also made subjective assessments of
alertness at the start and end of each work period
during the surveillance patrol using a self-rating form
that asked: “How alert do you feel?” Participants re-
sponded by placing a single stroke through a linear
bipolar visual analog scale (VAS) that consisted of a 100
mm line with the anchors “not at all” and “extremely”
at either end.

All participants shared the same work and flying
schedules for each day of the surveillance patrol. Flight
and work times were recorded in a work diary by the
author accompanying the aircrew.

Measures and Data Analysis

All data in the text appear as mean ± SD.

Melatonin onset: Salivary melatonin onset was used as
the marker of circadian phase. Participants may have
been exposed to sunlight during the period of saliva
sampling, so samples were not necessarily collected in
dim light. Consequently, the melatonin onset measure
cannot strictly be referred to as dim light melatonin
onset. Each participant’s mean (and standard deviation)
daytime melatonin concentration was determined us-
ing the early evening sample levels (i.e., samples until
20:00 h inclusive) from the baseline day and each day of
the surveillance patrol. Melatonin onset was defined as
the first time that a participant’s salivary melatonin
concentration exceeded and remained higher than their
threshold level, which was two standard deviations
greater than their mean daytime level (31).

For each participant, melatonin onset was deter-
mined for the baseline day and each day of the patrol.
Melatonin data from four participants were excluded
from the analysis because melatonin concentrations
were particularly low for each day of the patrol such
that onset times could not be determined. The other
participants’ cumulative phase shift for each day of the
surveillance patrol was calculated as the difference be-
tween baseline melatonin onset and melatonin onset for
that day. t-tests were used to compare the cumulative
phase shift on (a) the baseline day and day 6 (after
traveling 3.5 time zones east), and (b) day 6 and day 12
(after returning 2 time zones west).

Sleep/wake: The following measures were extracted
from the sleep diary and activity monitor data:
• Sleep onset time: the clock time that a participant fell asleep.
• Wake up time: the clock time that a participant woke to end a sleep period.
• Sleep duration: the period between sleep onset time and wake up time, less awakenings.
• Subjective sleep quality: a participant’s self-rating of sleep quality on a scale of 1 (very good) to 5 (very poor).
• Actual wake percentage (objective sleep quality measure): the wake within sleep period, divided by the period between sleep onset time and wake up time, multiplied by 100.
• Mean activity score (objective sleep quality measure): an index of the magnitude of activity during sleep periods. Specifically, it is the sum of the activity counts between sleep onset time and wake up time divided by the number of epochs between sleep onset time and wake up time.

For each measure, t-tests were used to compare the differences between rest days and workdays, and between sleep at home and sleep away from home.

Subjective alertness: Alertness scores from VAS forms were normalized within participants with z-transformations to control for inter-individual variation. The normalized data were then analyzed using two separate factorial ANOVA. The first factorial ANOVA, which was used to assess the effect of prior sleep duration on alertness at the start of a work period, had one factor (prior sleep duration) with five levels. The second factorial ANOVA, which was used to assess the effect of flight duration on alertness at the end of a work period, had one factor (flight duration) with four levels.

RESULTS

Melatonin Onset

The timing of salivary melatonin onset, sunrise and sunset, and sleep for each day of the study are represented in Fig. 1 (relative to Australian Central Standard Time). Note the timing of exposure to natural light over the study period. On days when the aircrew traveled east (i.e., days 1, 3, 4, and 6), dark occurred relatively earlier and those days were effectively shortened. Conversely, on days when the aircrew traveled west (i.e., days 7 and 10), dark occurred relatively later and those days were effectively lengthened. The duration of daylight was also affected, to some extent, by latitude such that days were longer the further north the aircrew traveled. For example, the aircrew traveled north on day 2, from latitude 19°17’ S to latitude 9°28’ S. Consequently, sunset was later and sunrise was earlier on night 2 than night 1, even though no time zones were crossed.

Mean melatonin onset occurred at 22:00 h on the baseline night (+9.5 GMT) compared with 18:10 h on night 6 (-11 GMT). Thus, there was a significant advance in melatonin onset of 3.83 ± 2.08 h following a series of time zone transitions totalling a 3.5-h shift to the east during the first 6 d of the surveillance patrol (t4 = 8.24, p < .0001). On night 12 (+11 GMT), mean melatonin onset occurred at 18:34 h, indicating a phase advance relative to baseline of 3.47 ± 1.32 h, or a phase delay of 0.4 h relative to night 6. Thus, following a series of time zone transitions totalling a 2-h shift to the west during the second 6 d of the surveillance patrol, the magnitude of the phase delay was not significant (t9 = -0.38, ns).

Sleep/Wake

The length and timing of main sleep periods and the average amount of sleep that participants obtained each day depended on whether or not they worked. On an average workday, participants fell asleep at 22:56 ± 1.73 h, woke prior to sunrise (05:33 h ± 0.65 h), and obtained 6.41 ± 1.71 h of sleep. Prior to rest days (nights 4, 8, and 11), participants fell asleep at 00:06 h ± 2.58 h, woke after sunrise (08:55 h ± 1.75 h), and obtained 8.36 ± 2.31 h of sleep. t-tests confirmed that sleep prior to workdays started and ended significantly earlier, and was significantly shorter than sleep prior to rest days (Table 1).

The difference in sleep/wake patterns between rest days and workdays is illustrated in Fig. 2. The top and
bottom panels represent the average distribution of work, sleep, and leisure periods across the 24-h day for workdays and rest days, respectively. On workdays, sleep periods (black area) generally occurred between 23:00 and 05:30. The activity period (gray area) generally occurred between 06:00 and 16:00, and leisure periods (white area) occurred in the remainder of the day. On rest days, there were no work periods, while sleep periods (black area) generally occurred between 00:00 and 09:00. The activity period (gray area) occurred in the remainder of the day. The figure demonstrates that more sleep was obtained on rest days, sleep onset and wake up times both occurred later on rest days, and the peak sleep probability time occurred later (06:00 h rather than 03:00 h) on rest days compared with workdays.

Sleep Quality
The results of t-tests to compare subjective sleep quality on workdays and rest days, and at home and away from home, are reported in Tables II and III, respectively. There were no significant differences in self-rated sleep quality or mean activity score on nights prior to a workday and nights prior to a rest day. In contrast, the actual wake percentage during sleep prior to a workday was significantly less than that prior to a rest day. The only home sleep that was recorded with activity monitors was prior to a workday (the night before the surveillance patrol began). Thus, home and away sleep periods prior to workdays only were compared. There were no significant differences in self-rated sleep quality, actual wake percentage, or mean activity score between sleep at home and sleep away from home.

Self-Rated Alertness
There was a tendency for self-assessed alertness at the start of a work period to increase as the amount of sleep obtained in the night-time sleep period immediately prior to it increased (Fig. 3). However, factorial ANOVA indicated that there was no significant effect of prior sleep duration on alertness (F<sub>4,120</sub> = 2.10, ns). There was also a tendency for self-assessed alertness at the end of a work period to decrease as the number of flying hours increased (Fig. 4). Again however, factorial ANOVA indicated that there was no significant effect of flying hours on alertness (F<sub>3,126</sub> = 1.99, ns).

DISCUSSION
The aim of the current study was to assess the biological adaptation of an RAAF aircrew to several small time zone transitions using salivary melatonin onset as the circadian phase marker, and to determine the effect of the aircrew’s work schedule on their sleep/wake patterns and subjective ratings of alertness. The results indicated that as the aircrew traveled eastward during the first 6 d of a surveillance patrol, melatonin onset occurred progressively earlier (i.e., phase advanced). Subsequently, as the aircrew returned westward during the second 6 d of the surveillance patrol, melatonin onset did not significantly shift. In addition, night-time sleep duration was shorter prior to workdays than prior to rest days, and subjective alertness was not significantly affected by either the duration of night-time sleep prior to work, or the duration of flight.

Circadian Adaptation to Transmeridian Flight
If participants had completely adapted to the time zone transitions throughout the surveillance patrol, there would have been a phase advance in melatonin onset of 3.5 h between nights 0 and 6 when initially flying eastward, and a phase delay of 2 h between nights 6 and 12 when subsequently flying westward. However, the phase advance was greater than that required for full adaptation (i.e., 3.8 h), and the subsequent phase delay was less than that required for full adaptation (i.e., 0.4 h) (Fig. 1). Thus, it appears that participants’ circadian timing systems adapted well to several small time zone transitions when initially flying eastward, but did not adapt particularly well to a similar pattern of time zone transitions when subsequently flying westward.

These results are contrary to expectations based on studies of single acute time zone transitions, which indicate that adaptation to westward flight is more...
Table II: T-Test Results for Workday—Rest Day Comparisons of Activity-Monitor-Determined Sleep Quality Measures (Mean ± SD).

<table>
<thead>
<tr>
<th>Measure</th>
<th>Workday</th>
<th>Rest Day</th>
<th>df</th>
<th>t-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-rated sleep quality</td>
<td>2.58 ± 0.95</td>
<td>2.35 ± 0.87</td>
<td>170</td>
<td>1.38</td>
</tr>
<tr>
<td>Actual wake percentage (%)</td>
<td>3.16 ± 2.21</td>
<td>4.06 ± 2.92</td>
<td>165</td>
<td>-2.06^</td>
</tr>
<tr>
<td>Mean activity score (average movement/epoch)</td>
<td>1.78 ± 1.14</td>
<td>2.22 ± 1.76</td>
<td>165</td>
<td>-1.59</td>
</tr>
</tbody>
</table>

^ p < 0.05, ^ p < 0.01, ^ p < 0.0001

Rapid than adaptation to eastward flight (9,11,29). However, this counter-intuitive finding may be attributable to factors other than a difference in the circadian timing system's ability to adapt to eastward and westward flight after several small time zone transitions.

Most importantly, the phase advance during the first half of the surveillance patrol may not have been solely due to time zone transitions. On the baseline day, the mean wake up time was 68 min after sunrise. In comparison, on workdays during the eastward period of the surveillance patrol, participants were required to wake early to maximize the time available to fly in daylight, such that the mean wake up time was 52–77 min prior to sunrise. Thus, participants woke 120–145 min earlier relative to sunrise on these days than on the baseline day. Consequently, there were two phase advance signals during the eastward period of the surveillance patrol: (i) the timing of the light/dark cycle shifted relatively earlier on each day that the aircrew flew eastward, and (ii) participants had greater exposure to sunlight in the morning on workdays than in their home time zone due to their earlier wake up times. Irrespective of time zone transitions, increased exposure to bright light in the morning provides a phase advance signal (3,20,21). Thus, the phase advance during the eastward period of the surveillance patrol may have been due, at least in part, to the earlier wake up times. This would explain why the magnitude of the phase advance (i.e., 3.8 h) was greater than the magnitude of the time zone shift (i.e., 3.5 h).

Furthermore, the lack of a significant phase delay in melatonin onset during the second half of the patrol may not necessarily indicate that adaptation to several small time zone transitions is poor when flying west. Rather, the compounding of time zone transitions and the rapid switch from phase advance to phase delay signals (i.e., eastward to westward flight) may have disrupted participants' circadian timing systems such that no significant phase shift was possible. To test this explanation, the current protocol could be repeated with the order of flight direction reversed (i.e., westward flight first, then eastward). Such a protocol would indicate whether the differential adaptation to westward and eastward flight observed in the current study was due to the direction of flight itself, or the order in which westward and eastward flight occurred. In addition, participants received both phase advance and phase delay signals during the second half of the surveillance patrol. While they flew west and the timing of the light/dark cycle shifted later (i.e., a phase delay signal), they were still waking early and being exposed to sunlight in the morning (i.e., a phase advance signal). Thus, the lack of a significant shift in salivary melatonin onset during the second 6 d of the surveillance patrol may have been due to these mixed signals.

Salivaary Melatonin as a Circadian Phase Marker

A major advantage of using melatonin onset as a phase marker is that the rhythm of melatonin production is not masked by the sleep/wake or activity/rest cycles (19,22,24). However, melatonin production is suppressed by exposure to bright light (23). In laboratory studies, this can be overcome by sampling melatonin in dim light to gain a measure of endogenous circadian phase independent of any exogenous influences. In field studies though, light exposure cannot be controlled in this way, so saliva samples are not always collected in dim light. This issue is a potential problem associated with the current study: saliva samples were not necessarily collected in dim light because collection began before sunset and participants could have been outdoors at that time. The potential effect of evening light exposure would have been to suppress melatonin production and thus artificially delay melatonin onset (23). This would have inhibited a phase advance during the first half of the surveillance patrol, and aided a phase delay during the second half of the surveillance patrol. However, exactly the opposite occurred: the initial phase advance was good, but the subsequent phase delay was poor. This indicates that the possible effects of suppression of outdoor light exposure in the evening did not interfere with the current results.

In the current study, the concentration of melatonin in saliva was determined using the RIA technique validated by Voultisios et al. (31). In addition, the method

Table III: T-Test Results for Home—Away Comparisons of Activity-Monitor-Determined Sleep Quality Measures for Workdays (Mean ± SD).

<table>
<thead>
<tr>
<th>Measure</th>
<th>Home</th>
<th>Away</th>
<th>df</th>
<th>t-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-rated sleep quality</td>
<td>2.79 ± 0.95</td>
<td>2.56 ± 0.95</td>
<td>131</td>
<td>0.86</td>
</tr>
<tr>
<td>Actual wake percentage (%)</td>
<td>2.74 ± 2.11</td>
<td>3.20 ± 2.23</td>
<td>127</td>
<td>-0.72</td>
</tr>
<tr>
<td>Mean activity score (average movement/epoch)</td>
<td>1.48 ± 1.11</td>
<td>1.82 ± 2.06</td>
<td>127</td>
<td>-0.34</td>
</tr>
</tbody>
</table>

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of calculating the threshold melatonin concentration for melatonin onset, i.e., two standard deviations above the mean daytime level, validated by Voultsios et al. (31) was used. The current results indicate that this RIA technique and threshold calculation method can be effectively used to determine salivary melatonin onset, thus providing an alternative method to core body temperature for the assessment of circadian phase shifts in field studies.

Sleep on Workdays and Rest Days

The average sleep duration prior to workdays was almost 2 h less than the average sleep duration prior to rest days. This highlights one of the most consistent findings regarding the sleep of shiftworkers: there is a pronounced reduction in the amount of sleep obtained on workdays compared with rest days (7,18,30).

While participants woke over 3 h earlier on workdays than they did on rest days, sleep onset occurred only a little over 1 h earlier prior to workdays. Thus, the early wake up time forced on participants by their work schedule caused a sleep restriction that was only partially compensated for by earlier sleep onset. Kecklund et al. (14) reported surprisingly similar results to these with polysomnographic assessments of shiftworkers’ sleep. They found that average sleep duration prior to early starts (i.e., before 06:00 h) was almost 2 h less than sleep duration prior to rest days, largely because a 3-h advance in wake up time was only partially offset by a 1-h advance in bedtime. The magnitude of sleep reduction associated with early starts is highlighted by Hak and Kampman (12), who found that even less sleep was obtained prior to an early shift than after a night shift. Folkard and Barton (6) suggest that the failure to compensate for earlier wake up times by going to bed earlier may not simply be due to social pressures to stay up, but may depend in part on Lavie’s (17) forbidden zone for sleep. However, in the current study, the expectation on aircrew to socialize with each other was an important factor in not going to bed earlier.

Sleep Quality

For two of the sleep quality measures used in the current study, i.e., self-rated sleep quality and mean activity score, there was no difference between rest days and workdays. In contrast, actual wake percentage was lower prior to workdays than rest days, indicating that sleep quality was higher prior to workdays. This was an unexpected result, given that the research indicates that the quality of shiftworkers’ sleep is typically disrupted when they have to start work early in the morning (1). In fact, Hak & Kampman (12) report data indicating that sleep quality may actually be more disturbed prior to early shifts than after night shifts. However, not all the research with aircrew supports this notion. For example, Kecklund et al. (14) found no difference in self-rated sleep quality before rest days and early shifts (i.e., start before 06:30 h), albeit in a commercial rather than a military setting.

There are a number of possible explanations for this unexpected finding in the current study. First, sleep on rest days was often extended into the mid-morning, a time of day at which it may be interrupted by circadian or environmental factors. In the mid-morning, core body temperature increases and sleep propensity is low (25). In addition, light, heat, and noise may interrupt sleep at this time of day. Second, there are physiological limits on the amount of sleep that may be obtained in any one sleep period such that it is difficult to extend sleep beyond 10–11 h, irrespective of the amount of prior wakefulness (28). Once this limit has been reached (which occurred on rest days, but not workdays), sleep will be more disturbed. Finally, participants generally consumed more alcohol the night before a rest day than a workday. It is a common belief that alcohol consumption aids sleep, but the literature indicates that while alcohol may aid sleep onset, even low blood alcohol concentrations cause disturbed sleep, especially in the latter half of a sleep period (16). Each of these three factors may have affected sleep such that a smaller percentage of the sleep period prior to rest days was actually spent sleeping compared with workdays, thus increasing the actual wake percentage.

Typically, sleep during layovers in short-haul flight
operations is of poorer quality than sleep at home (8). In the current study however, there were no differences between sleep quality at home and away from home for any of the three measures. The quality of many shift-workers' sleep is poor when they are away from home because they have to sleep in conditions that are less than ideal (e.g., onboard, in barracks, etc.). In the current study however, participants slept in hotel rooms that were cool, dark, and quiet (i.e., conducive to good sleep). Furthermore, for nine participants who usually lived with a partner and/or young children, being away from home may have actually removed a potential source of sleep disruption. In addition, participants may have developed strategies to cope with sleeping away from home because they had been doing these types of missions for an average of over 6 yr. Thus, the relative comfort of their sleep environments, the absence of the usual distractions of home life, and their experience with these types of missions, may have been sufficient to offset any disruptions associated with sleeping in unfamiliar surroundings, such that the quality of participants' sleep was not significantly disturbed.

Self-Rated Alertness

While there was no significant effect of prior sleep duration on subjective alertness at the start of a work period, there was a tendency for subjective alertness to be below average after sleeps of 5–6 hours or less (Fig. 3). The research indicates that restricting the length of sleep lowers its recuperative value such that alertness (and performance) may be impaired (4,5). In the current study, the duration of participants' sleep was limited due to (a) work periods beginning very early in the morning, (b) eastward flight making days shorter and reducing the time off between consecutive work periods, and (c) the expectation to participate in social activities in the evening.

While there was no significant effect of flight duration on subjective alertness at the end of a work period, there was a tendency for subjective alertness to fall as time on task increased (Fig. 4). This is consistent with research showing that self-assessed alertness falls as time at work increases (9), and that self-ratings of fatigue increase with progressing flight duration (27).

CONCLUSIONS

The current study provides an example of the application of salivary melatonin onset as a marker of circadian phase in a field-based study. The RIA technique and threshold calculation method validated by Voutsinos et al. (31) were successfully used to determine the magnitude and rate of circadian adaptation to a number of small time zone transitions. There was a phase advance greater than expected during the eastward section of the surveillance patrol and a phase delay less than expected during the westward section. In addition, night sleep duration was shorter prior to workdays than prior to rest days; there were no effects of sleep location on subjective or objective measures of sleep quality; and subjective alertness was not significantly affected by either the duration of night sleep prior to work or the duration of flight. Further research is required to determine whether the counter-intuitive finding regarding circadian phase shifts occurred because (a) biological adaptation to several small time zone transitions actually occurs more quickly after eastward than westward flight, (b) the compounding of time zone transitions and the rapid switch from phase advance to phase delay signals disrupted participants’ circadian timing systems, or (c) the sleep schedule forced on participants by the pattern of work provided a phase advance signal in addition to the eastward time zone transitions.

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