Sleep Deficit and Stress Hormones in Helicopter Pilots on 7-Day Duty for Emergency Medical Services

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Introduction: Helicopter-based emergency medical services in Germany operate from sunrise to sunset, requiring up to 15.5 h of continuous duty during the summer months for pilots, who work for seven consecutive days. Because of concerns regarding the safety of this procedure with respect to pilot fatigue and stress, the German Ministry of Transport asked our laboratory to investigate the risks involved. ***Methods:*** There were 13 pilots (mean age 38 yr) who were studied in the summer months for 2 d before, 7 d during, and 2 d after their duty cycle. Measured variables included sleep duration and quality, subjective fatigue, and heart rate, as well as 24-h excretion levels of stress hormones. ***Results:*** During actual helicopter operations, maximum heart rates did not exceed 120 bpm. Over the 7-d duty period, mean sleep duration decreased from 7.8 h to 6 h or less, resulting in a cumulative sleep loss of about 15 h. Mean levels of excreted adrenalin, noradrenalin, and cortisol increased significantly by 50 to 80%; cortisol and noradrenalin excretion also remained elevated for the two post-duty days. ***Conclusions:*** Although the actual flights did not cause critical physiological responses, the acute and accumulated sleep deficit led to incomplete recuperation between duty hours and induced elevated stress indicators. It was, therefore, recommended that the duty cycle be amended as follows: 1.) enforce a 10-h rest period and at least an 8-h sleep opportunity per day; 2.) modify the duty period to allow no more than 3 consecutive rest periods of reduced sleep opportunities (8.5 h); and 3.) follow duty with several days that offer unrestricted sleep opportunities.

Keywords: emergency medical services, helicopter pilots, flight duty, rest, sleep, stress, work load.

PROLONGED AND irregular work hours are a common phenomenon of modern society. Various occupations increasingly demand 24-h services, e.g., transportation, electronic communication, health care, and entertainment (3), and many companies have extended their daily work schedules to more than 8 h to accommodate this demand (16). Often, compressed work weeks are scheduled, extending the shift time to even $12 \text{ h} \cdot \text{d}^{-1}$. There are many diverse reasons for this. For example, some industries (e.g., aviation, shipping) routinely schedule long periods of work, followed by extended periods of rest, because the exchange of personnel is impractical; others (e.g., emergency and health services) have a shortage of qualified staff and are frequently using employees working overtime. Extended work shifts can, however, lead to excessive fatigue and compromise performance, productivity, efficiency, and safety. Fatigue depends on the time of day of work, long duration of wakefulness, inadequate sleep, pathological sleepiness, and prolonged work hours (1). It causes performance decrements and can generate errors and accidents (4).

Another common phenomenon of modern society is the curtailment of sleep, regardless of whether caused by very long day-time duty shifts, shift work including night shifts, or voluntarily extending wake times. Average sleep time lies in a range between 7.5 and 8 h (12,15). Shortening sleep length leads to sleep deprivation and subsequently—depending on the amount of sleep reduction—to mild, moderate, or severe sleepiness and fatigue, progressively affecting behavior and performance (5,8,23). Sleep deficit becomes a critical safety issue when operators are responsible for transportation or manufacturing systems (13,14).

In the aviation environment, sleep deficit is often accompanied by disruptions of the circadian system due to irregular work hours, jet lag, and night work. The impact of shifted sleep-wake cycles, desynchronized circadian rhythms (jet lag), and disturbed sleep on alertness and performance of aircrew has been investigated during long-haul and short-haul operations on various routes (9,11,18–20,22). So far, only a few scientific investigations have been performed with respect to sleep behavior and fatigue during pilot duty in helicopter operations. In rotary wing operations, Gander et al. investigated flight crew fatigue (7). They observed 32 helicopter pilots on North Sea air transport operations during duty cycles of 4 or 5 consecutive days who operated during the daytime. Results indicated earlier (1.5 h) awakenings on duty days than on off-duty days, a reduction in sleep duration by nearly 1 h, and enhanced fatigue after duty. Furthermore, sleep quality decreased and mood was impaired (7). Consecutive long duty hours, combined with short rest periods and consequently short sleep duration, cause detrimen-

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tal effects on sleep, fatigue, and health, even when only two double-shifts are performed in a row (10).

Since 1970, the Federal Republic of Germany has had a helicopter-based emergency rescue system. Helicopters are based at major hospitals in a service network such that every point in Germany is at a distance of no more than 70 km from a station. Thus, the helicopter service can promptly react to severe accidents within a couple of minutes. Because the helicopter-based system can act much faster than the ground-based counterpart, it reduces the morbidity and mortality of patients after the initial severe injuries have occurred. Originally introduced as a rescue system for the German motorways/freeways (Autobahn), in the meantime their tasks broadened to helping with various kinds of serious accidents. The bases operate on a "stand-by mode," i.e., the medical personnel and the helicopter pilots are reacting "on call."

Since most of the helicopters are not equipped with night flight capabilities, daylight hours, i.e., the time between dawn and dusk, limit the operation of the emergency helicopters. Depending on the season, this time interval varies from 8 h (winter solstice) to 16 h (summer solstice). Consequently, the long daylight periods of the summer months lead to long duty hours and reduced rest times. In Germany, flight duty period (FDP), duty time, and rest times are regulated by compulsory rules (2) that apply to all civil aviation modes (both fixed and rotary wing operations). For example, a standard FDP of 10 h can be extended, with certain restrictions (20). Since these rules do not allow duty periods of more than 10 h for single pilot operations (and require a minimum rest of 10 h per each 24-h period), there is a conflict between these rules and the often life-saving and, therefore, imperative duty of the emergency rescue helicopter pilots. However, German regulations allow exemptions from their rules if special circumstances occur (2). For helicopter-based emergency rescue (primary rescue operations), providers of the system regularly apply for such an exemption. The justification to receive permission for an exemption is that pilots work "on call" only during their duty period. It is assumed that there are sufficient opportunities for breaks between actual flight and service operations to compensate for such long duty hours. Under unfavorable conditions, i.e., in the summer time when daylight exceeds 12 h, and dense traffic conditions may cause several accidents per day (esp. during school holidays), a pilot may be on duty up to $15.5 \text{ h} \cdot \text{d}^{-1}$, followed by a rest time of 8.5 h per night. Since a duty period comprises several consecutive duty days, these conditions may lead to an overburdened work load, accumulated stress, and fatigue, without adequate recuperation during rest. Because such a practice may compromise flight safety with respect to human error, the DLR-Institute of Aerospace Medicine investigated these duty rosters on behalf of the German Ministry of Transport. Two studies were performed using physiological and psychological measurements taken during actual duty cycles that provide recommendations for a safer mode of operation of the helicopter-based primary rescue system. The first study is the subject of this report. The main objective of this first study was to investigate whether the practice of the "7 d on-duty/7 d off-duty" roster that includes very long duty days is adequate with respect to work load, fatigue, and stress of the pilots, and also to safety aspects of primary medical emergency rescue helicopter operations. In the event of negative findings, recommendations should be proposed for changes in these very special operations and for the flight-time limitation (FTL)-rules.

METHODS

Initially, the records of emergency helicopter pilots during a previous summer period, which contained reports on flight duty and rest times, were studied. Using these actual flight duty and rest times, an optimal time frame for data collection was determined that included the peak holiday season in summer. A German automobile club (ADAC) with seven rescue helicopter stations located throughout Germany was contacted for recruitment of subjects. There were 13 male pilots, 38 yr ± 3.9 yr of age (mean ± SD), from the ADAC who volunteered for the field study after having given informed consent, which complied with the Helsinki Declaration. All pilots, having been closely medically monitored according to the law, were accepted without any inclusion or exclusion criteria. They represented almost all the medical emergency helicopter pilots currently employed, and all seven stations were included in the study. Each station covered an action radius of about 70 km.

The investigations took place from June to September at the various helicopter bases with study periods of 11 d each. Observers were with the pilots during all study periods, visiting them at their homes and, if facilities permitted, even sleeping at the stations. The pilots were on a duty roster of 7 d on-duty and 7 d off-duty. Recording of data began 2 d before another duty phase started, i.e., on the 6^{th} d of a pilot's leisure time, which was considered the baseline day. After 2 pre-duty days, all 7 duty days, and 2 post-duty days were investigated for a total of 11 d.

The pilots usually spent their off-duty days at their own homes. Regardless of where, investigators observed them during the pre- and post-duty days by daily visits to the pilots in their familiar environments. During their on-duty periods, however, most pilots preferred staying at their stations. Since the stations were usually linked to hospital compounds, they were fully equipped so that it was possible to live on the premises. Besides the helicopter maintenance facilities, the stations had fully furnished individual bedrooms, kitchens, social rooms with TV, and offices. At a given time only a single pilot per station was on duty and could be observed during his 7 d on-duty by an investigator who also stayed at the station. Except for any necessary refuelling and/or maintenance of the helicopter, pilots on call were free between tasks to do office work, to nap, to prepare meals, to watch TV, to chat, etc. At dawn they had to prepare the helicopter for flight, and by dusk of each on-duty day they had to carry out post-flight maintenance and safe parking of the aircraft in the hangar.

During the 11-d monitoring period, the following physiological parameters were investigated: continuous signals of ECG were directly digitized; and heart rate by beats per minute was calculated, registered, and stored in 60-s intervals all day and night. The activity of the non-dominant wrist was recorded during sleep, directly digitized and stored in 60-s intervals. Data from both variables were stored on miniature devices (ZAK, Simbach, Germany). ECG devices were carried constantly, and actometers were carried at night only, without bothering the pilots. Heart rate was analyzed for the time intervals during emergency helicopter flights in order to access the physical load. The monitoring of wrist activity during sleep served as a control for the ratings in the sleep logs with respect to sleep onset and wake-up time, and sleep duration. In addition, stress hormones (cortisol and catecholamines) were investigated by collection of total urine at 3-h intervals during wake and after sleep, and subsequent biochemical analysis. Psychological measurements were recorded twice a day (morning and evening) by a sleep log that included subjective sleep parameters (sleep onset, wake-up time, sleep duration and sleep quality, and need for further sleep) and the rating of total work load of the duty day (18). The activity data were used to check the subjective data concerning sleep onset and wake-up time. Pilots filled in a fatigue checklist (21), Stanford Sleepiness Scale (SSS), and visual analogous scales (VAS) for tension and alertness at 3-h intervals during waking hours.

The statistical calculations were made by analysis of variance (ANOVA) within subjects with repeated measurements. To compare baseline and the consecutive duty and post-duty days, the Student's paired *t*-test was applied. Correlations between sleep log and activity data were calculated by Pearson's correlation coefficient. To examine possible coherences between fatigue, sleepiness, and alertness levels, data were analyzed by Spearman's rho correlation coefficient. Significance for all statistical analyses was set for $p \leq 0.05$. Data analyses were performed using the SPSS statistical package (version 11.5, SPSS Inc, Chicago, IL).

RESULTS

Days of Operation, Flight Duty Period, and Rest Times

Pilots were consecutively scheduled in a 7-d work-on work-off rhythm, i.e., they were 7 d on-duty and 7 off-duty. The examination of the records of the pilots between May and September showed 927 duty days out of a possible 1989 d. On average, each helicopter pilot served 14.3 duty days per month. The highest value was reached in July with 16.5 d. Per duty day, the FDP was usually between 5 and 6 h, depending on the operating station and the number of emergency flights. The legal FDP of 10 $h \cdot d^{-1}$ (2) was exceeded by 9.8% of all duty days during the investigated period of 5 mo; the maximum excess (14%) occurred in August. More than 11 h FDP was performed on 4.6% of operation days, and more than 12 h FDP on 3.4%. Out of the 927 investigated duty days, even 14 h FDP was exceeded on 4 d.

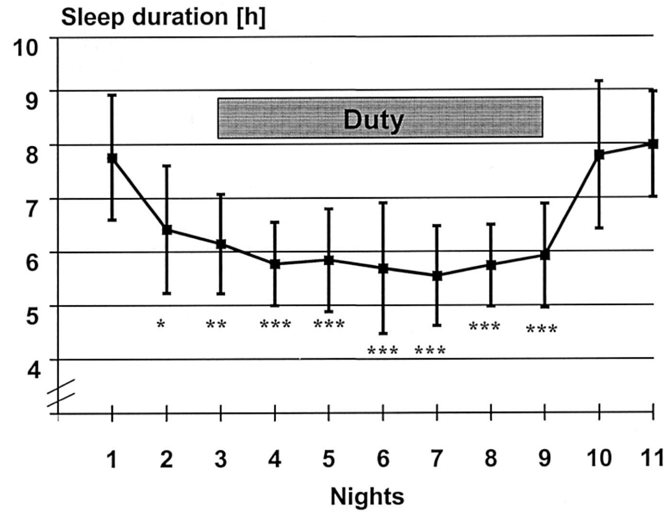

Fig. 1. Sleep duration (n = 13). Nights 3–9 = duty (* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$; Student's paired *t*-test).

Long duty hours can lead to reduced rest times. The records show that from May until July, more than 95% of the rest times were less than 10 h, in August 85%, and in September 10%. Thus, whereas in May and August the available time for rest per duty day was mainly between 9 and 10 h, in June and July the majority of pilots got only between 8 and 9 h for rest per duty day.

Sleep

Sleep was measured by actigraphy and subjective ratings. Comparison showed that both methods led to nearly congruent results with respect to sleep duration: the mean difference was less than 15 min; Pearson's correlation coefficient was $r = 0.924$ ($p \leq 0.001$). During the duty period (7 d), sleep was significantly shortened compared with control (**Fig. 1**).

Whereas pilots slept 7.8 h ± 1.2 h at home (nights 1, 10, and 11), average sleep duration was reduced by 2.2 h during duty. Thus, the mean sleep deficit accumulated to 8.9 h after 4 d of duty and to 15 h over the entire 7-d duty period. During night 2 (before commencing duty), some pilots slept less (1.4 h on average) due to early wake-up, since they had to travel to their helicopter stations. Detailed analysis of sleep duration during duty nights showed that 55% of sleep durations were less than 6 h, 33% less than 5.5 h, 15% less than 5 h, and 6% less than 4 h.

Early awakenings were mainly responsible for shortened sleep durations. When comparing the time-in-bed times, pilots usually went to bed between 23:30 and midnight (mean = 23:45, SD = 0:13), regardless of whether at home or at their station. However, during duty, they got up between 05:45 and 06:00 (mean = 05:54, SD = 0:06), whereas at home they slept until 07:38 ± 0:14 h, except on day 2, when they got up at 06:45 in order to travel to their emergency stations. Asked for any reason why they had not gone to bed earlier on duty days in order to achieve more sleep, they argued that they needed some time to unwind from duty.

Sleep latencies decreased constantly and significantly

TABLE I. 24-H MEAN EXCRETION RATES OF ADRENALIN, NORADRENALIN, AND CORTISOL (N = 13). VALUES ARE NORMALIZED FOR EACH SUBJECT RELATIVE TO DAY 1 (=100%).

Study Day	Duty Day	Adrenalin		Noradrenalin		Cortisol	
		Mean	SD	Mean	SD	Mean	SD
1		100	0	100	0	100	0
2		108	32	110	28	130*	39
3	1	153**	49	121	42	147**	41
4	2	150	95	149**	52	185**	69
5	3	151**	58	158**	49	182***	53
6	4	152*	63	153*	64	173***	51
7	5	153*	67	143*	48	176***	44
8	6	131	64	145**	41	167***	44
9	7	140	72	143*	52	176**	73
10		131	84	144*	47	176***	29
11		107	52	125*	40	146***	30

Deviations from control are presented in percent (*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$; Student's paired *t*-test).

during duty days (days 3–9, F = 39.334, $p \leq 0.001$, repeated measurements ANOVA). Latencies were 27.5 min ± 25.8 min on day 3, 15.6 min ± 9.4 min on day 6, and 11.1 min ± 6.4 min on the night before the final duty day (day 9). The shorter sleep duration led to enhanced ratings for more sleep. Compared with baseline, pilots rated their need for more sleep significantly higher on study days 4 to 8, i.e., duty days 2 to 6 ($p \leq 0.05$).

Naps can help maintain alertness and performance during sustained duty (5,17). However, in this study, pilots took naps only very rarely during their on-call duty. Only two naps per day were taken on study days 4, 5, 6, and 9 (i.e., duty days 2, 3, 4, and 7), whereas on days 7 and 8 (duty days 5 and 6) the number of naps increased to four and five, respectively. With elapsed time of the duty week, the average duration of napping time increased from 6 min (duty day 2) to 30 min (duty day 7).

Work Load, Fatigue, and Stress

On average, pilots had 5.2 flight missions per day (ranging from 3.6 on duty day 1 to 6.5 on duty day 4). Subjective ratings of work load on a visual analog scale between 0 (no work load at all) and 50 (extreme work load), completed every evening after the end of duty, showed increments. On duty day 1 (study day 3), work load ratings were as low as 16.8 points ± 14.2; the maximum was reached on duty day 7 (study day 9) with 29.9 points ± 11.5. Statistical analysis exhibited a significant deviation (to higher work load) on duty day 4 (mean = 24.2, SD = 8.6 points; $p \leq 0.05$), duty day 5 (mean = 24.7, SD = 13.4 points; $p \leq 0.05$), and duty day 7 (mean = 29.9, SD = 11.5 points, $p \leq 0.001$).

Fatigue ratings were assessed by means of a checklist, ranging from 0 (very alert) to 20 (very fatigued) (19–21). In the morning at home (pre- and post-duty) the scores were between 7.0 and 7.3 (SD ranging from 2.6 to 3.6). During duty, the morning values ranged from 7.9 (duty day 7) to 8.5 (duty day 5); SD was between 3.1 and 4.3. The corresponding mean evening values ranged from 10.6 and 11.6 (at home, SD between 2.6 and 4.0), and during duty between 10.0 and 12.1 (SD between 2.7 and 4.0). Thus, a significant change in self-rated fatigue was not detected. Furthermore, in the SSS and the alertness VAS, significant differences between on-duty and off-duty days were not observed. The correlation (Spearman) between the fatigue checklist (FAT), the SSS and the VAS was high (FAT vs. SSS: r = 0.811; FAT vs. alertness VAS: r = −0.737; SSS vs. VAS: r = −0.811).

During their emergency flight operations, individual pilots showed very divergent heart frequencies. The minimum values differed between 57 bpm and 85 bpm, the maximum values between 76 bpm and 120 bpm. In eight pilots, the maximum mean heart rate was between 100 bpm and 120 bpm. In a very few cases during flight, short-term elevations up to 140 bpm were observed. In the other five pilots, the maximum heart frequency was between 76 and 97 bpm during helicopter operations.

As overall stress indicators, 24-h mean values were calculated for the excretion rates of adrenalin, noradrenalin, and cortisol. In **Table I**, deviations from control (day 1) are depicted. Adrenalin showed enhanced excretion rates on duty days 1 and 3 ($p \leq 0.01$), and on duty days 4 and 5 ($p \leq 0.05$), respectively. Significant increments of noradrenalin started on duty day 2 until the end of duty and remained elevated 2 d beyond. The changes were significant on a level of $p \leq 0.05$ or $p \leq 0.01$ (Table I). Cortisol excretion rates exhibited significant increments during all duty days and did not reach baseline values within the two follow-up days of investigation. These increments were moderately ($p \leq 0.01$) to highly ($p \leq 0.001$) significant.

In addition, as indicators for the recuperation of the short sleep periods, nocturnal excretion rates of the stress hormones were also investigated. They showed several significant increments only in the noradrenalin excretions during the duty periods, whereas adrenalin and cortisol exhibited no significant changes. Noradrenalin excretion rates were significantly elevated in the morning after all duty days, except duty day 4 (study day 6) (days 3, 5, 7, 8, and 9: $p \leq 0.05$; day 6: $p \leq 0.01$). On average, noradrenalin excretion concentrations increased by 32% during duty nights.

DISCUSSION

Emergency medical helicopter services in Germany have a long tradition and have led to rapid and successful interventions after severe road accidents. The nature of these services implies very challenging operations. Environmental conditions include very long duty days, immediate response to emergencies, uncommon, ill-suited, and unknown landing sites (e.g., on or near highways), unfavorable weather conditions, and all aspects of dealing with severely wounded or ill humans, or even casualties. Thus, both the operational and emotional load can be very high. This study focused on the operational constraints connected with this life-saving system. This investigation in particular examined the work load and recuperation opportunities of the flight crew with respect to the current flight, flight duty time, and rest requirements in Germany (6). To our knowledge, it is the first study of its kind.

The analysis of the distribution of daily flight duty hours indicates that the current duration does not lead to serious problems for the pilots. Usually, a flight duty period of 5 to 6 h—the mean value in this study—is acceptable. In some cases (7 to 14%, depending on the month of operation), flight duty periods of more than 10 h occurred. These cases were often connected with a very busy emergency station which had to cope with many more emergency operations than the others due to its geographical location in Germany.

Taking into account physiological results during duty days (ECG recordings) and the subjective ratings of work load, it can be concluded from the results that the flying task per se does not impose a severe burden. Although some of the measured stress parameters showed elevated reactions during the course of the 7-d duty period, these reactions are within a range that can be assessed as being "normal" to "moderately severe," but not "extreme." However, the flight duty period exclusively does not reflect the entire work environment of the helicopter pilots. It is just a part of the duty time that is needed to perform their tasks at the stations. Since daily on-call duty commenced at 06:30 and ended by dusk in the summer months, pilots were assigned to duty up to 15.5 $h \cdot d^{-1}$. Consequently, rest times were shorter than 10 h. This happened 85 to 99% of the time during the summer, depending on the month. In conjunction with reduced rest times, sleep duration was impaired. From a control value of 7.8 h, it dropped to less than 6 h per night during the duty period of 7 d. In some cases, pilots even slept less than 4 h. It was found that a sleep deficit of 15 h on average occurred by the end of the 7-d duty period. The cause for this reduction of sleep, however, cannot be attributed solely to the prolonging of duty hours and the subsequent shortening of the rest times, since the mean rest time duration was about 9 h, which allows for a longer sleep duration than 6 h. Obviously, the rest time did not completely prevent sleep deficits. Because of the early start of the daily duty period (at 06:30), crew were compelled to awaken substantially earlier than they were used to at home during off-duty days. However, they failed to shift the start of sleep to earlier times as well, in order to compensate for early starts, and kept their habitual bedtime (about 24:00). The reason for this behavior can be seen in the need for some time between duty completion and bedtime (2–3 h) to be spent "unwinding" from duty with social activities as well as for personal hygiene. This was different in the North Sea helicopter study by Gander et al. (7); there, pilots had a duty time of 7.1 $h \cdot d^{-1}$ and a night-time layover of 16.9 $h \cdot d^{-1}$ on average. Therefore, they had the opportunity to more easily shift their sleep onset to earlier times, although a daily sleep loss of 0.8 h remained.

Naps can improve alertness and performance during subsequent duty (5,17). But in this study, during days on duty, naps were only sparsely used to reduce the sleep loss, as was also the case in the study by Gander et al. (7). Some guidance on the detrimental effects of sleep loss could lead to improvements in sleep hygiene. In contrast to investigations performed on pilots during long-haul operations (19,22), when those pilots rated their fatigue as increasing with ongoing sleep loss and/or long duty hours, that was not the case in this study. It could be suggested that the pilots studied here were reluctant to admit increasing "on-the-job" difficulties.

The decrease in sleep latencies, the elevation of nocturnal excretions rates of the stress hormone noradrenalin, and the increments of the morning rating concerning sleep need during the 7-d duty period indicate an enhanced vulnerability caused by sleep loss. The increments of excretion rates of all investigated stress hormones on a 24-h scale during duty showed that the combination of long duty days and short rest opportunities reflected an increment of stress that was further confirmed by the work load scorings after duty days. With conclusions drawn from investigations in other industries where the effects of long or very long work hours on fatigue, stress, and performance were studied (16,19), a higher risk for incidents must be assumed (4), although that was not investigated in this study.

CONCLUSIONS

The results of this investigation clearly indicate that the shortness of rest times with the progress of a duty period of 7 d that consequently resulted in reduced sleep times is the main reason for increased strain and stress, whereas the flight operations generally do not contribute to the same extent. Therefore, the most important issue for recommendations is to address the problem of rest. In general, the minimum rest requirements of the German flight time regulations should be enforced, i.e., a 10-h rest period and at least an 8-h sleep opportunity (2). However, with respect to the special conditions of the emergency medical helicopter operations, an exemption from this general rule can be recommended; i.e., a curtailment of rest times to not less than 8.5 h per night is acceptable under the following conditions: 1.) 8 h must be granted at the location where pilots will sleep (in order to guarantee a minimum sleep opportunity of 8 h); and 2.) curtailment of rest to 8.5 h is only allowed for three consecutive nights, and afterwards, several nights should be granted for unrestricted sleep opportunities. Additional recommendations are as follows: 1.) if a flight duty period exceeds 11 h, a curtailment of rest (below 12 h) is not allowable; and 2.) pilots should be trained with respect to adequate sleep hygiene. In the meantime, the main recommendations have been adopted by the German Ministry of Transport.

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