Fatigue in Two-Pilot Operations: Implications for Flight and Duty Time Limitations

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Objectives: Two-pilot operations make up the majority of commercial flights. Fatigue is an important consideration in these operations as there is little opportunity for in-flight rest. We investigated the role of duty length, time of day, and whether one or two sectors were flown on reported fatigue at the top of descent in two-pilot regional operations. ***Methods:*** Pilots flying two-pilot operations ranging from 3-12 h completed Samn-Perelli fatigue ratings prior to descent at the end of each rostered duty over a 12-wk period. We collected 3023 usable ratings (72% of rostered duties) comprising 26% single and 74% double sector duties. ***Results:*** We found that time of day has a marked effect on the pattern of fatigue at the start of the duty and on the rate at which fatigue levels increased, with the highest levels in the window of circadian low (0200–0600). Fatigue also increased with the length of duty and was 0.56 higher at the end of a two-sector compared with a single-sector duty. ***Discussion:*** The results imply authorities should consider increasing existing limits for daytime duties and reducing those for nighttime two-pilot operations.

Keywords: pilots, time of day, work hours, circadian rhythm, duty time limitations.

MANAGING FATIGUE is an important component of commercial airline operations. Two-pilot operations, which represent the majority of commercial flights, present a particular challenge due to the lack of opportunity for pilots to use in-flight rest (1). Often two-pilot duties may be in excess of 10 h, operate through the night, and have critical stages of the flight during periods of circadian lows. Furthermore, there are few scientific studies available to guide the development of flight and duty time limitations, which to date have mostly been set arbitrarily through regulation or industrial agreement.

In order to develop more scientifically based flight and duty regulations it is important to understand how fatigue in two-pilot operations is influenced by factors such as the time of day, the number of sectors flown, and whether the flight is returning or traveling away from the pilots' home base. While previous research has highlighted that the overall risk of aviation accidents is associated with longer duty periods (2), it is not clear what duty period is optimal at any given report time to minimize the chance of hazardous levels of fatigue.

The majority of previous research on pilot fatigue has focused on long-haul flights operated with augmented crews and there is comparatively little work on two-pilot operations. Early research on long two-pilot duties was conducted on crews flying between Germany and the Seychelles at night (5). This study highlighted the low levels of alertness that can arise at the end of 9-10 h two-pilot flights, but it is difficult to generalize from these specific flights to operations of varying durations at different times of day. Other studies have also looked at particular operations (4), but it is not easy to develop general principles from this research about the influences of factors such as duty length and time of day on fatigue. Such work would be useful for identifying two-pilot duties that are likely to have high levels of fatigue and to guide the development of more scientifically based schemes for flight and duty time regulations.

In a recent study of pilot fatigue in short-haul operations where the top of descent was between 0800 and 2200 we found the most important influences on pilot fatigue were the number of sectors and the length of the duty period (3). The nature of the domestic operation with no overnight flying means that the results are difficult to apply to other two-pilot operations that fly through the night. In the current study we examined the role of duty length, time of day at the top of descent, and whether one or two sectors were flown. Similar to our previous study, we collected alertness ratings from pilots at the end of their last duty sector just prior to the top of descent. This enabled us to determine the relative importance of these factors at a critical stage of the flight. Rather than focusing on specific flights or operations, this study used data from a large number of duties of variable duration and timing, but involving sectors of similar lengths. Using this approach, we can move toward establishing duty time limitations based on fatigue considerations.

METHODS

The investigation was conducted from January 1 to March 31, 2003. Here we report the findings on two-pilot operations flying 1 or 2 sector duties that ranged from 3

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to 12 h duty time. Individual sectors were between 3 and 5 h. Data were gathered from pilots operating Boeing 737-300, 767, and 747-400 two-pilot operations.

During the study period there were a total of 4206 two-pilot duties between New Zealand and destinations within Australia and the Pacific Islands. All pilots were sent a letter explaining the study and inviting them to participate in the research. Pilots were asked to complete a brief anonymous questionnaire at the top of descent on the last sector of the duty. Details of the questionnaire and methodology have been described previously (3), and involved pilots recording the duty start time, time at the top of descent, and the sectors flown. Pilots also rated their fatigue on the 7-point Samn-Perelli scale (6), ranging from 1 "fully alert, wide awake" to 7 "completely exhausted, unable to function effectively," and on a 100-mm visual analogue scale rated "alert" to "drowsy."

Statistical Methods

The analysis was restricted to duties with one or two sectors, where the 'duty time', defined here as the time between report and top of descent, was between 3 h and 12 h. Returns were also excluded where times were missing, inconsistent, or unreliable. The data were then analyzed by a stepwise least squares (analysis of variance and regression) procedure. The factors included in this analysis were: length of duty, covering duties between 3 h and 12 h ($N = 9$); time of day at top of descent, at 1-h intervals ($N = 24$); the number of sectors, either one or two ($N = 2$); and the type of duty, either departing from or returning to New Zealand, or a round trip ($N = 3$). Interaction terms were only included if the relevant main effects were significant.

Where duties commenced outside New Zealand, time zone differences were small (typically 2 h or less) and layovers were brief (1 or 2 nights). Therefore, we defined the time of day relative to local time in New Zealand. Alternative definitions were considered to account for possible adaptation to local time where the departure airport was in a different time zone. These included the assumption of complete adaptation to local time prior to departure, complete adaptation up to a maximum of 2 h, and 50% adaptation to local time. However, as all these assumptions led to an increase in the residual sum of squares, they were not considered further.

Contrasts within the main effects were included as regressor variables in the form of polynomials (length of duty) and harmonics (time of day). However, polynomials of higher degree than a cubic, and harmonics beyond the second, were not considered. Where the contrast or contrasts accounted for the significant differences within a factor, they replaced that factor in subsequent analyses, including in the interaction terms. This procedure was used to generate an equation of best fit to the subjective data. The graphical representation of the main effects in this paper has been derived from a model in which the terms have been taken from the equation of best fit. Finally, the fitted equation was used to derive trends in fatigue related to duty start time.

The analysis was carried out on both the visual analogue data and on the Samn-Perelli scores. However, these two variables were closely related, with a Pearson correlation coefficient of 0.89, and the results of both analyses were similar. Therefore, only the results from the Samn-Perelli data are presented here.

RESULTS

There were 3181 questionnaires returned (72% response rate), and these were reduced to 3023 after the application of the exclusion criteria. On average pilots completed fatigue ratings on six occasions, but as the survey was anonymous, the exact number for individual pilots cannot be determined. Of the duties, 26% were single sector and 74% two sector. The breakdown by type of duty was as follows: 12% departing from New Zealand, 20% returning to New Zealand, and 68% round trip. Reporting and top of descent occurred at all times of day. However, the commonest reporting times were between 0500 and 0600 (17%), between 1400 and 1600 (24%), and between 2000 and 2200 (9%). Top of descent occurred most frequently between 0400 and 0600 (15%), between 1400 and 1500 (15%), and between 2300 and 0000 (18%). The median duty length was 8.2 h, and the lower and upper quartiles were 7.1 h and 9.0 h, respectively.

All four factors (time of day, length of duty, number of sectors, and type of duty) contributed significantly to levels of fatigue at top of descent (see **Table I**). With regard to time of day, fatigue followed a standard circadian pattern with fatigue levels highest in the early hours of the morning and lowest in the early evening (**Fig. 1**). Mean levels related to type of duty varied between 3.88 (round trip), 4.04 (returning to New Zealand), and 4.23 (leaving New Zealand). The main effect of length of duty ($P < 0.001$) was explained by quadratic trend where the increase in fatigue was greater for shorter than for

TABLE I. THE CONTRIBUTION OF VARIOUS TERMS TO THE EQUATION OF BEST FIT.

		In Model Order		Included Last	
Factor or interaction	df	% Total Sum of Squares	Significance	% Total Sum of Squares	Significance
Time of day	4	24.23	$P < 0.001$	20.48	$P < 0.001$
Length of duty	2	11.30	$P < 0.001$	3.66	$P < 0.001$
Sectors	1	0.13	$P < 0.05$	0.45	$P < 0.001$
Type of duty	2	0.51	$P < 0.001$	0.24	$P < 0.01$
Time of day x length of duty	6	1.55	$P < 0.001$	1.50	$P < 0.001$
Sectors x length of duty	2	0.23	$P < 0.01$	0.23	$P < 0.01$

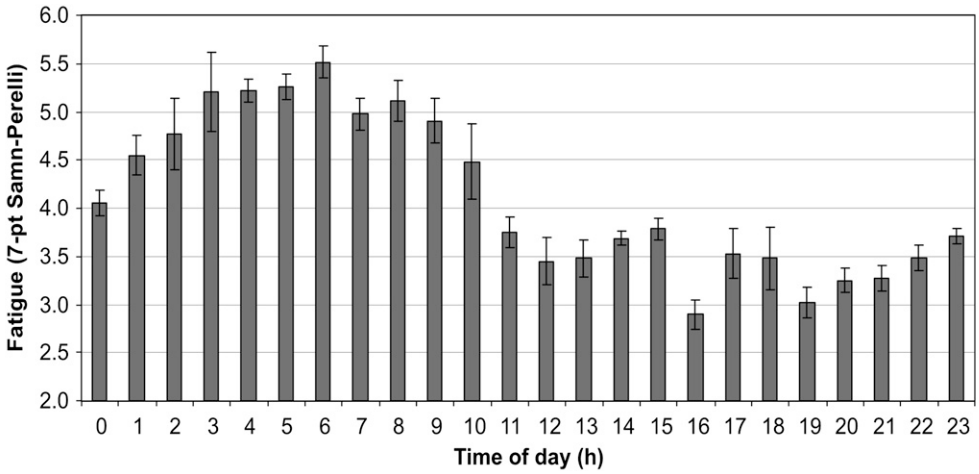

Fig. 1. The main effect of time of day on subjective fatigue at top of descent. Error bars correspond to ± 1 SEM.

longer duties. With respect to sectors, two-sector operations were associated with fatigue levels that were 0.56 higher than single-sector operations.

In addition to the main effects, two interaction terms were significant. The effect of the length of duty varied with time of day ($P < 0.001$), as is shown in **Fig. 2**. Thus there was little increase among duties ending between 0300–0600 as fatigue levels are high for all lengths of duty; this contrasts with duties ending between 1200–1500, where the effect of time of duty was substantial. There was also a significant interaction between length of duty and the number of sectors flown ($P < 0.05$). The increase in fatigue with duty length was more evident in single-sector than in two-sector operations.

The contribution of the various factors and interaction terms to the best-fitting model of fatigue at the top of descent is presented in Table I. We have described the contribution of the factors where the individual terms have been added in sequence (in model order) and where the terms have been added in the presence of the other significant factors (included last). The time of day component is represented by a 24-h sinusoidal function together with the second harmonic, and the length of duty by a quadratic function of time. For the time of day by length of duty interaction, the second harmonic of time of day crossed with the quadratic component of length of duty has been excluded, as it did not contribute significantly to the overall fit. Terms up to and including the second harmonic explained 95% of the variance associated with time of day, and a quadratic trend explained 99% of the variance associated with length of duty.

In order to demonstrate the effect of start time on the progression of fatigue we looked at start time in 3-h intervals (**Fig. 3**). There are marked differences at different times of day in both the fatigue level after 3 h duty and the rate at which fatigue increases. For duties starting at 0300, fatigue is at a moderately high level after only 3 h duty, but changes little with duty length. In contrast, a short duty starting at 1800 ends with little fatigue while a 12-h duty ends with high levels of fatigue. Duties commencing later at 2100 or 0000 reach fatigue levels above 5 after only 6-7 h of duty, whereas duties starting at 0300 do not reach this level, even after 12 h.

DISCUSSION

This study examined pilot fatigue at the top of descent across routine commercial two-pilot operations. We found time of day, length of duty, the number of sectors, and the type of duty (to or from home base) all contributed significantly to the level of fatigue at the top of descent. The strongest influence on fatigue was time of day with the highest levels in the window of circadian low (0200–0600). As anticipated, fatigue also increased with the length of duty and the number of sectors flown. We further found duties involving a trip away from home base were

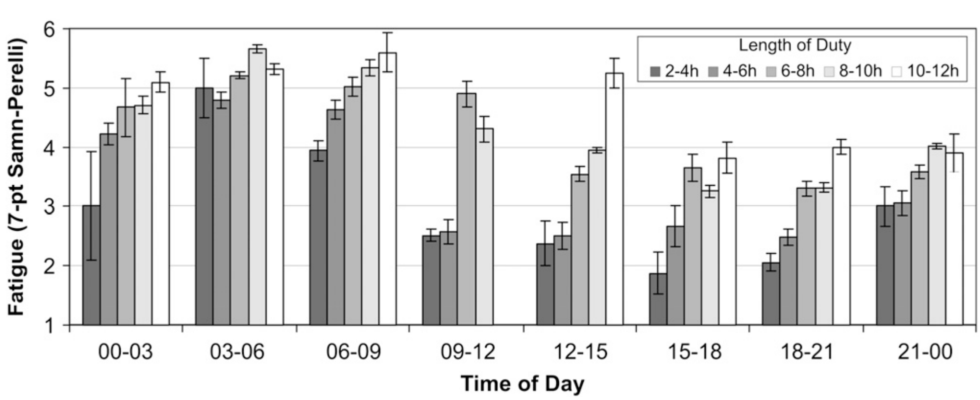

Fig. 2. The combined effect of length of duty and time of day on subjective fatigue at top of descent. Error bars correspond to ± 1 SEM.

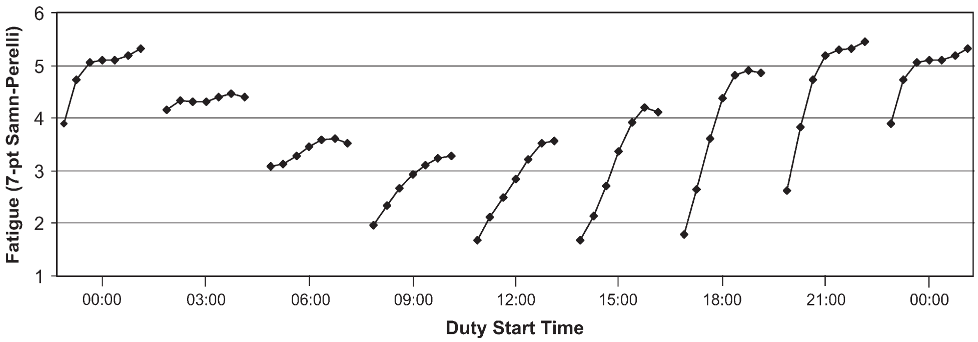

Fig. 3. Trends in fatigue with increasing length of duty, for duties starting at different times of day. The seven points on each curve relate to lengths of duties of 3 h, 4.5 h, 6 h, 7.5 h, 9 h, 10.5 h, and 12 h, respectively.

associated with slightly increased levels of fatigue, but it is possible that this may be influenced by the pattern of work preceding the duty rather than the duty itself.

The study also found that the effect of the length of duty depended on the time of day at the top of descent. When this effect was translated into report time we found that time of day has a marked effect on the overall level of fatigue at the start of the duty and on the rate at which fatigue levels increase. While existing flight time limitations such as CAP371 and EU regulations make a relatively minor distinction between day and night (2–3 h duty time), the fatigue patterns we have found exhibit a much greater difference. For example, we have seen the level of fatigue after 12 h for duties starting between 0600 and 1200 is already exceeded after 3 h when the duty starts between midnight and 0300. The finding of this study would suggest relaxing the limits for daytime duties and tightening those for two-pilot nighttime duties. Other studies also point to a circadian effect greater than is reflected in current limitations but are based on a less comprehensive dataset (7).

The results are also broadly consistent with our recent study of short-haul multisector operations (3) which found a similar relationship between time of day and length of duty; however, the current study extends this analysis to cover the full 24-h period. Furthermore, the effect of an additional sector was similar in both studies despite markedly different sector lengths. Since the results were corrected for duty length, this effect may be due to the workload associated with an additional approach and landing.

It should be noted that the current study is based on pilot subjective reports and no performance testing was carried out. We did not include information about in-flight napping or operational considerations that may have influenced workload. Furthermore, the study is limited by a lack of information about the pattern of work immediately preceding duty. While it is difficult to see how this would systematically confound the results, this possibility cannot be excluded.

However, there are several aspects of the study that support the validity of the results. As a result of the simplicity of the methodology, it has been possible to collect information from a very large number of flights. In addition the response rate is considerably higher than in most comparable studies where participation has relied on pilot volunteers. While the data have been collected from one airline operation, it has been possible to study duties of different duration covering all times of day, and this has enabled greater confidence to be placed in the parameters of the fitted model. In conclusion, this study has provided a snapshot of all two-pilot medium-range duties from a single operator, and the derived trends in the build-up in fatigue have important implications for flight-time limitations.

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