

Pilot Fatigue in Short-Haul Operations: Effects of Number of Sectors, Duty Length, and Time of Day

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Introduction: There is little research on what factors are associated with fatigue in short-haul pilots. The aim was to investigate how length of duty, number of sectors, time of day, and departure airport affect fatigue levels in short-haul operations. **Methods:** Pilots completed Samn-Perelli fatigue ratings prior to descent at the end of each rostered short-haul duty over a 12-wk period. Overall, 1370 usable responses were collected (67% of rostered duties) and fatigue scores were examined in relation to the departure airport, the number of sectors flown, time, and the length of duty period. **Results:** The most important influences on fatigue were the number of sectors and duty length. These were associated with fatigue in a linear fashion. Time of day had a weaker influence, with lower levels at midday and increased fatigue later in the day. Fatigue was also higher during duties originating from an airport where pilots needed to position the night before and spend the night in a hotel. **Discussion:** Data from the study enabled the quantification of fatigue at this critical phase of flight in duties lasting between 2 and 12 h and finishing between 08:00 to 24:00. The data obtained may be useful for identifying factors associated with fatigue, evaluating existing fatigue models, and identifying or predicting problem duties within an airline operation. The methodology used in the study may be successfully applied to gather fatigue data in other airline operations.

Keywords: fatigue, short-haul, work hours, time of day, circadian rhythm.

FATIGUE IS AN important influence on pilot performance in commercial airline operations. To date, most research activity has focused on transmeridian international operations, where tours of duty involve long sectors and travel across several time zones. There has been comparatively little research on fatigue in pilots flying short-haul operations, although the work pattern of these pilots often has a number of factors associated with increased reports of fatigue. Pilots flying short-haul operations are often rostered for an irregular pattern of early starts and late finishes, which can disrupt normal sleep routines and increase fatigue. In contrast to long-haul flying, the work pattern may involve multiple takeoffs and landings, resulting in a more demanding workload across the workday. Furthermore, short haul flying is carried out by two-pilot crews so there are no in-flight rest opportunities and this has been shown to result in higher fatigue levels than three-pilot crews (4).

Surveys have suggested fatigue is a common problem in short-haul commercial pilots (2,6), with pilots identifying extended duty periods and successive early

starts as the most important causes (2). Short-haul rosters cause pilots to sleep less, wake earlier, and have less restful sleep over the work period (5). Studies with UK pilots have identified time of day and the number of flights per day as important influences on the development of fatigue during the course of a short-haul duty period (3). It is clear from the small amount of research conducted with short-haul crew that early starts, late finishes, and the high workload caused by multiple sectors are important influencing factors on fatigue levels. However, it is not clear which factors contribute most, particularly at the most critical period for flight safety—the final approach and landing phase. This information would be valuable for planning work schedules in order to minimize the risk of fatigue.

In this study we investigated the relative importance of these factors in predicting fatigue at the end of the work period. Whereas previous studies have relied on taking performance and physiological measures on a small number of pilots, we collected alertness ratings from a large number of pilots toward the end of their last duty sector. This enabled us to quantify the relative importance of time of day, number of sectors flown, duty start time, and duty length on fatigue levels at this critical stage.

METHODS

The study was conducted during a 3-mo period from January 1 to March 31, 2003, on Air New Zealand Boeing 737 operations. At the time this fleet operated 15 Boeing 737–300 aircraft on sectors within New Zealand ranging from 30 min to 100 min flight time, but the great majority of sectors were between 45 and 75 min. All pilots on the 737 fleet were sent a letter from pilot

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management notifying them of the study and asking them to consider participating in the research. Over the study period there were a total of 2034 duties with at least 1 operating sector. During the data collection period pilots were asked to complete a brief anonymous questionnaire at the top of descent on the last sector of the duty day. Pilots recorded duty start time, current time (top of descent), and number of sectors flown across the day. Pilots also completed the 7-point Samn-Perelli fatigue scale (9) where they rated themselves as: 1 "fully alert, wide awake"; 2 "very lively, responsive but not at peak"; 3 "OK, somewhat fresh"; 4 "a little tired, less than fresh"; 5 "moderately tired, let down"; 6 "extremely tired, very difficult to concentrate"; or 7 "completely exhausted, unable to function effectively" as well as a 100-mm visual analog scale rated from "alert" to "drowsy." The questionnaires were placed in a special envelope on the aircraft which was returned to the Medical Unit.

The times corresponding to duty start and top of descent were verified, and data were excluded where these times were missing, inconsistent, or unreliable. The data were then analyzed by a stepwise least squares procedure. The factors included in this analysis were: duty length, defined as the duration of the period between report time and top of descent; time of day at the top of descent; the number of sectors; and the de-

parture airport. Interaction terms were only considered for inclusion if the relevant main effects were significant.

As part of this procedure, contrasts within the main effects were included as regressor variables in the form of polynomials (duty length and number of sectors) and harmonics (time of day). Where the contrast or contrasts accounted for all the significant differences within a factor, they replaced that factor in subsequent analyses, including in the interaction terms. 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. Differences between individual means were tested using the Newman-Keuls multiple range test. The analysis was carried out on both the visual analog data and on the Samn-Perelli scores. However, these two variables were closely related, with a Pearson correlation coefficient of 0.86, and the results of both analyses were similar. Therefore, only the Samn-Perelli data are presented here.

RESULTS

There were 1466 questionnaires returned, giving a response rate of 72% of total duty periods, and these were further reduced to 1370 (67%) after the application

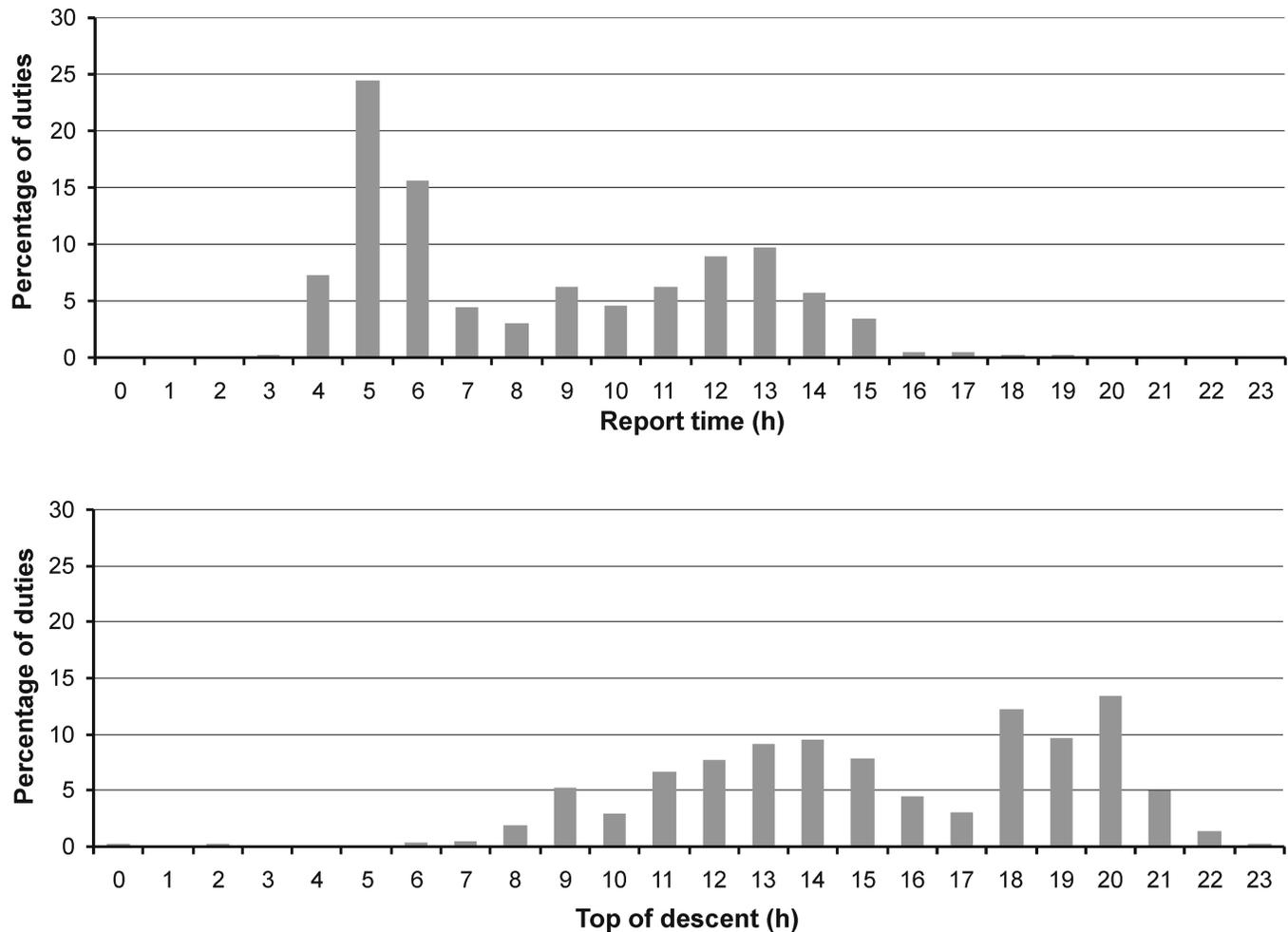


Fig. 1. The time-of-day distributions of report times (top) and of times corresponding to the top of descent (bottom).

of the exclusion criteria. Most duties originated in Auckland (39%), followed by Christchurch (32%), Wellington (21%), and Dunedin (8%). The total number of sectors varied between one and five, with most flights comprising four (37%) or five (30%) sectors. The distributions of the report times and of times corresponding to top of descent are shown in Fig. 1. Almost half of all report times were before 07:00, while a further 30% were between 11:00 and 15:00. The most frequent time periods at top of descent were between 11:00 and 16:00 (41%) and between 18:00 and 21:00 (35%). The average duty time, defined as the time between report and top of descent, was 7.2 h (minimum 1.1; maximum 11.2).

Reported fatigue at the top of descent was explained by the length of the duty, the number of sectors, and the time of day at the top of descent. The main effects of all four factors—airport of origin, length of duty, time of day, and number of sectors—were significant ($p < 0.001$). The mean values are plotted in Fig. 2, after correcting for the other components of the best fit. The main effect of airport was demonstrated by the flights departing from Dunedin and Wellington, which were associated with higher levels of fatigue than those departing from Auckland ($p < 0.001$) or Christchurch ($p < 0.05$). The effect due to the number of sectors was linear, and the increase in fatigue associated with each additional sector was equivalent to an increase of 0.38 on the 7-point Samn-Perelli scale. The influence of duty length on fatigue was also best expressed by a positive

linear function of duty time. The influence of time of day on fatigue was best expressed by the first two harmonics of time of day. The only interaction that contributed to the equation of best fit was between duty length and the first harmonic of time of day ($p < 0.001$). The fitted trends defined by this term are plotted in Fig. 3 and show that after midday there is a general increase in fatigue with time of day and this increase is particularly strong after 22:00.

Pilots who commenced duty early in the morning reported higher levels of fatigue. The increase in fatigue with duty length was larger before and just after midday than later in the evening, when average levels of fatigue, even at the end of a short duty, were generally highest. However, it should be noted that the interaction only accounts for a small amount of the overall variance.

The importance of the individual factors can be quantified by the size of their contribution to the total variability. The contribution of each factor was: number of sectors (33.3%); duty length (33.0%); time of day (12.6%); airport of origin (3.2%); and the interaction between duty length and time of day (1.4%). The total variance explained by all factors combined was 40.8%. As duty length and time of day are not independent, the combination of duty length and time of day shown in Fig. 3 gives the best illustration of the influence of these important factors on overall fatigue levels.

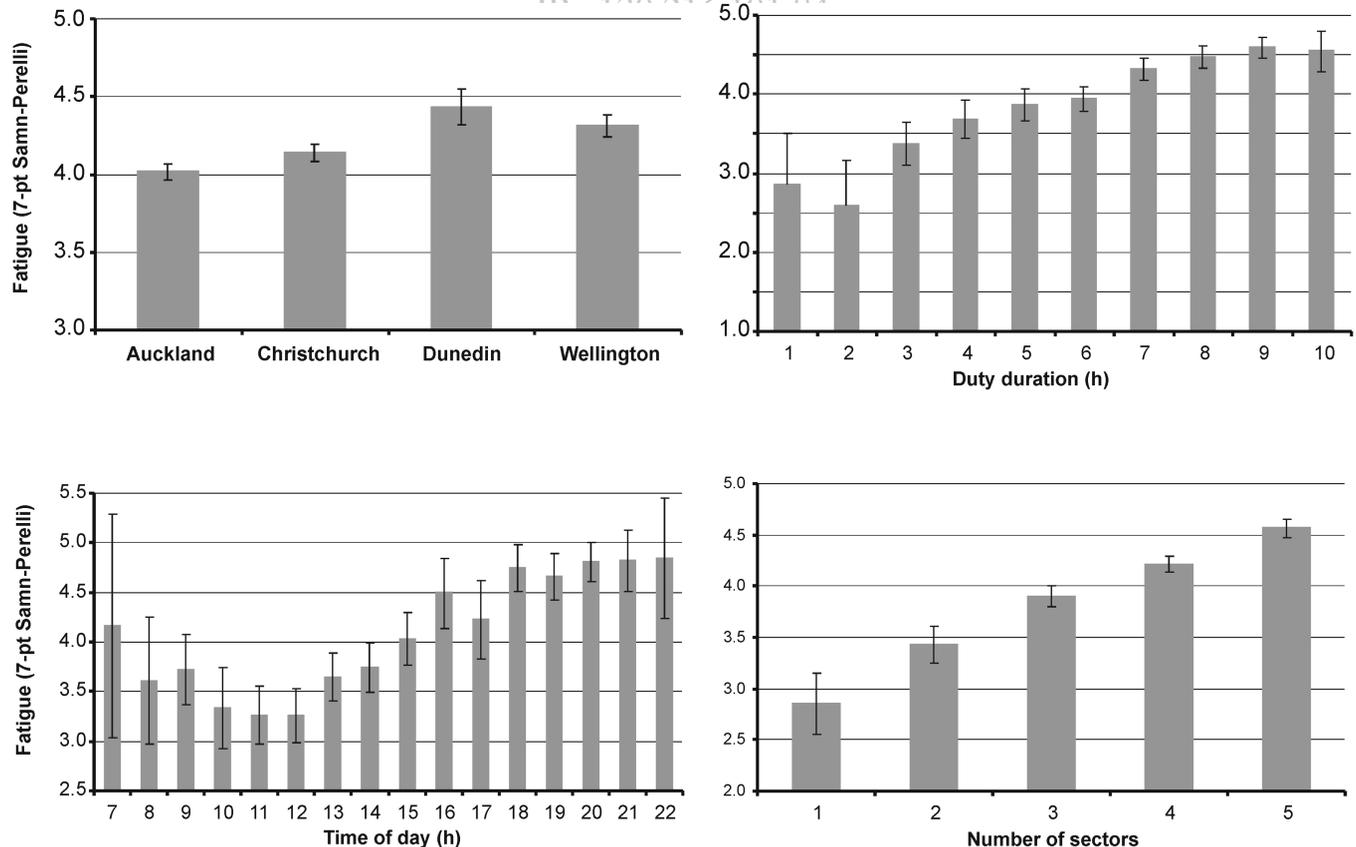


Fig. 2. The main effect of four factors that have a significant effect on levels of fatigue at the top of descent: the departure airport (top left), the length of duty (top right), the time of day (bottom left), and the number of sectors (bottom right). Error bars correspond to ± 1 SEM.

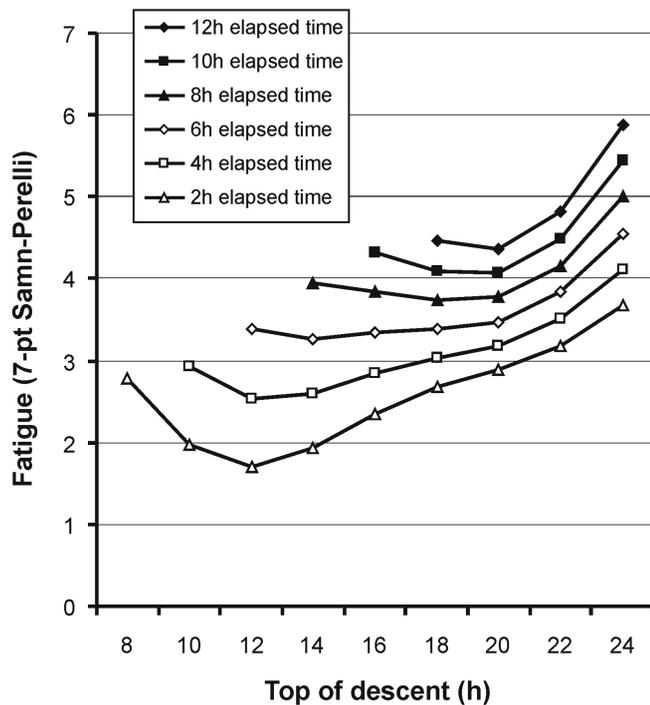


Fig. 3. Fatigue at the top of descent related to time of day and the length of duty: the trend lines are derived from the equation of best fit.

DISCUSSION

We found pilot fatigue in short-haul pilots at the end of their last duty sector was significantly influenced by length of duty, time of day, the number of sectors flown, and airport of departure. The most important influences on fatigue were the number of sectors and duty length, which in this particular operation are very closely related. Duty length and the number of sectors increased fatigue in a linear fashion. Time of day had a weaker influence, with lowest levels at midday and an increased level of fatigue later in the day. The data showed that the most favorable time of day for the last landing depended on the duty length. For shorter duties the most favorable time for the last landing was around midday, whereas for longer duties, the best time was 20:00. The higher levels of fatigue found in pilots departing from the Dunedin and Wellington airports were probably due to pilots being required to position the previous day and stay overnight in a hotel, as opposed to Auckland and Christchurch, which are home bases for the pilots.

These results are consistent with three studies carried out on domestic UK pilots using a different methodology (3). These previous studies also showed the importance of the individual effects of sector and time of day throughout the course of the duty. In this study we looked in more detail at the critical phase of the duty from a safety perspective and we found that fatigue cannot be represented as a simple summation of the individual factors. This reflects the complex interaction between, on the one hand, the timing of duty related to the circadian rhythm of fatigue and, on the other hand, the duration of duty and its impact on the timing of sleep. Typically, a mean value of 5 on the Samn-Perelli scale gives rise to some concern about the suitability of

that particular roster (9). As illustrated in Fig. 3, this value is reached after 8 h elapsed time when the top of descent is around midnight.

This study had several strengths including a large sample and good response rate, as well as collecting data at a critical phase of flight rather than retrospectively. However, there are a number of methodological issues relevant to the interpretation of the results. Firstly, fatigue was measured using subjective pilot ratings rather than using objective indices, such as reaction time tasks. However, the Samn-Perelli scores have been shown to follow similar trends to objective measures throughout a duty period (8). Secondly, all the data were collected on domestic sectors of a similar length with no overnight duties and no time zone changes, so they may not be directly applicable to different operations. It is also likely that this lack of overnight duties attenuated the time of day effect as highest levels of fatigue tend to occur in the early morning (3).

The study has a number of implications for research and fatigue models. There are several mathematical models designed to predict fatigue levels in pilots operating short-haul operations (1,7). Data from this study will enable further validation of these models in actual airline operations. Furthermore, the study demonstrated that collecting fatigue data through a brief questionnaire at a critical time in the workday across an airline operation is feasible, and produces reliable and useful data. For example, Fig. 3 can be used to predict fatigue across duties of various lengths at different times of the day. This study shows the usefulness of such data for identifying the factors associated with fatigue patterns, but also for identifying problem duties and providing a metric for identifying overall levels of fatigue across an operation.

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