# Personal and Work Factors That Predict Fatigue-Related Errors in Aircraft Maintenance Engineering

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**BACKGROUND:** The study aimed to identify factors associated with an increased likelihood of aircraft maintenance personnel reporting a fatigue-related error.

**METHODS:** There were 966 maintenance engineering personnel (mean age = 42 yr, 98% male) who completed a survey with items on personal factors, work factors and a question asking whether during the last month they had made an error in their work due to tiredness. Logistic regression analyses were used to determine factors independently associated with making an error at work due to tiredness.

**RESULTS:** Respondents obtained on average 7.0 h sleep and nearly half (45%) reported that they had felt close to falling asleep while driving home from work in the past 12 mo. Most respondents (70%) had received no education on strategies for coping with shift work. Among respondents, 22% agreed/strongly agreed with the statement "During the last month, I have made an error in my work due to tiredness." Unexpected roster changes independently predicted the likelihood of reporting an error in work due to tiredness and for certain groups of aircraft maintenance personnel, < 6.5 h sleep increased the odds of an error in work due to tiredness fivefold, whereas > 7.5 h sleep almost halved the odds of reporting such an error.

**DISCUSSION:** These findings indicate the importance of stable and predictable work patterns to minimize the risk of fatigue-related errors in this safety critical environment, and also the need for education on coping with shift work to ensure the workforce are best placed to manage their sleep away from work.

**KEYWORDS:** fatigue, fatigue risk, aviation, roster changes, stable work patterns, sleep.

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It is recognized that minimizing and preventing error in aircraft maintenance engineering is a key aspect of maintaining the integrity of the aviation safety system.[19] A number of tasks performed in aircraft maintenance engineering, particularly those of a cognitive nature, are likely to be adversely affected by fatigue.[20] In a previous study exploring the types of errors made by aircraft maintenance personnel and factors contributing to these errors, fatigue was found to be one of the top five contributing factors.[12] In addition, fatigue had a strong association with errors involving memory lapses (omitting an intended action) and perceptual failures (failure to detect information that was being sought). Fatigue as a concept is often poorly understood, but in this instance, is defined as "a physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness, circadian phase, or workload (mental and/or physical activity) that can impair a person's alertness and ability to perform safety-related duties."[14]

Due to the services provided and the nature of the aviation industry as a whole, aircraft maintenance engineers necessarily work shifts, with their hours of work often covering the 24-h day. Any shiftwork results in sleep being displaced, resulting in health and safety challenges not found in day work. The strong preference for sleep at night and wakefulness during the day is driven by the circadian biological clock, located in the suprachiasmatic nuclei of the brain, and keeps daily cycles in physical, mental and emotional functioning in step with the day/night cycle.[17] The circadian clock seldom adapts fully to altered work

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patterns, because it is sensitive to the unchanged day/night cycle and activities of the day-active society.[3] Thus shiftworkers, and particularly night workers, are working through the least functional part of the circadian cycle and sleeping at less than optimal times during the day. Previous research has demonstrated that after correcting for the number of people at work, errors in aircraft maintenance engineering demonstrate a 24-h rhythm, with a peak on the night shift between 02:00 and 03:00.[13]

There is also an international trend for this workforce to work extended shifts in order to compress the work week,[18] which has previously been demonstrated to result in increased levels of reported fatigue.[8] Extended work periods reduce the time available for all activities outside work. This can increase the risk of not getting enough sleep, leading to degraded alertness, performance and mood.[1,6,16] Extended work hours also have the potential to reduce safety margins because they can increase time-on-task fatigue.[2] Fatigue can accumulate to higher levels by the end of an extended work period, particularly if the workload is high and opportunities for breaks are limited.[1,2]

Compared to the amount of published literature on flight crew, there is less information available on the work patterns of aircraft maintenance personnel (engineers, mechanics and technicians) and the consequences for their sleep, sleepiness and work performance. As part of a larger study on human factors issues in aircraft maintenance engineering, information was collected on personal and work factors that might affect the work safety and performance of individuals working in this environment and contribute to a fatigue-related error at work.

As stated by Hobbs and Williamson,[12] error reduction strategies are most effective when targeting specific errors and their contributing factors rather than human error in general. The aim of this study was therefore to identify specific personal and work-based factors that related to fatigue-induced errors. By doing so, appropriate error mitigation strategies can be identified and employed.

## METHODS

The study was reviewed and approved by the Massey University Human Ethics Committee (application 05/15) and was conducted in collaboration with representatives from the Quality Assurance department of the participating aircraft engineering service at a large airline. Quality Assurance department representatives were responsible for informing employees of the study, particularly the processes being used to ensure respondent anonymity, data confidentiality, and feedback of the results.

Three aircraft engineering sites were involved in the study and there were three different groups of aircraft maintenance personnel: Technical Certifying staff worked directly on aircraft and/or their components and were able to certificate completed work; Technical Noncertifying staff worked directly on aircraft or their components and may have had delegated authority or no authority to clear work cards; and Management and Technical Support staff worked in, or managed, technical areas. Within each of these groups, staff were classified as either: Aircraft Maintenance, which involves conducting scheduled maintenance on aircraft or components that have been removed from service for this purpose; or Line Maintenance, which involves completing tasks on aircraft that are in operation.

### Materials

Two questionnaires were distributed. The first questionnaire was the Safety Health in Maintenance Engineering (SHoMe) questionnaire. SHoMe was developed by Health and Safety Engineering Consultants Ltd on behalf of the United Kingdom Civil Aviation Authority.[5] The results of the questionnaire indicate areas where an organization is more susceptible to human error or where other human factor problems might occur. This was the focus of the larger study from which the data presented here were drawn.

The SHoMe questionnaire comprises four sections: job details, generic questions, organizational questions, and questions on aspects of the job which cause difficulties. Quality Assurance department representatives reviewed the questionnaires to ensure the questions and terminology were appropriate for the workforce. In the present study, only responses from a single item in the generic questionnaire were utilized. This item was "During the last month I have made an error in my work due to tiredness," with respondents indicating on a 5-point scale from "strongly agree" to "strongly disagree." Two items in the job details questionnaire were utilized: shift type (permanent days/permanent nights/rotating) and number of hours worked in a typical week ($<$ 40, 40-50, 50-60, 60-70, $>$ 70 h).

The second questionnaire, which was developed specifically for the present analyses, focused on sleep and included items relating to personal factors (demographics, length of commute to work, sleep and sleepiness) and work. Questions on sleep and sleepiness included the number of hours of sleep usually obtained in 24 h; frequency of getting enough sleep; and frequency of waking up feeling refreshed (never/rarely/often/always). These questions were selected from previously used surveys of sleep habits of adults[11] and shiftworkers.[10] Respondents were also asked if they had felt close to falling asleep while driving home from work in the last 12 mo (yes/no). The Epworth Sleepiness Scale (ESS) was also included, which is a validated questionnaire that measures daytime sleepiness by means of assessing the likelihood of falling asleep in eight situations commonly encountered in daily life.[15] An ESS score $>$ 10 indicates excessive daytime sleepiness.

Work-related questions included the frequency with which a respondent: was provided with adequate breaks during a shift; worked longer than a rostered shift; was called back to work on scheduled days off; and had unexpected roster changes (never/rarely/often/always), and whether the respondent had been provided with education on coping with the effects of shift work (yes/no). These questions were selected from a nationwide survey of New Zealand junior doctors.[10]

### Procedure

The research team assigned a unique study ID number to each employee and only the study ID number was printed on each of the questionnaires. Questionnaire packs containing both questionnaires, a cover letter describing the study and a prepaid return envelope were enclosed in a sealed envelope, labeled with the employee's name and staff number. These questionnaire packs were distributed to the aircraft maintenance employees by line managers.

Questionnaires were returned to the research team via sealed collection boxes in the workplaces or in a prepaid return envelope provided. Employees were provided with time at work to independently complete the questionnaires. Two weeks following the initial distribution, a reminder postcard was sent to all employees whose completed questionnaires had not yet been received. After a further 2 weeks, new questionnaires were sent to the remaining nonresponders.

### Statistical Analyses

All data were double entered by two independent researchers, checked for errors, and any discrepancies resolved. Descriptive statistics and tests for differences between groups were analyzed using the Statistical Package for Social Sciences (Version 12.0.1 for Windows, SPSS Inc., Chicago, IL). Continuous variables were not normally distributed; therefore, the Kruskal-Wallis and Mann-Whitney tests were used to compare groups. Chi-squared tests were used to compare categorical variables.

Not all respondents completed each question on the questionnaires. Those who did not answer a particular question were excluded from the analysis of that variable but included in all other analyses. Due to possible differences in the type and organization of work, comparisons were made between Technical Certifying, Technical Noncertifying, and Management and Technical Support staff. Where appropriate, comparisons were also made between Aircraft Maintenance and Line Maintenance staff irrespective of their roles as Technical Certifying or Technical Noncertifying staff.

To investigate the relationship between the outcome (reports of error at work due to tiredness, derived from the SHoMe questionnaire), and a range of personal and work factors, logistic regression analyses were performed in SAS (version 9, SAS Institute Inc., Cary, NC). Responses on the question "During the last month I have made an error in my work due to tiredness" were dichotomized to "strongly agree/agree" or "strongly disagree/disagree." Those who responded "not sure" ($N = 137$), or who did not answer the question ($N = 3$) were not included in the analyses.

Additionally, the following four variables were categorized: age: $< 40$ yr and $\geq 40$ yr; length of commute: $\leq 15$ min (25.2% of respondents); 16–30 min (51.4% of respondents), and $> 30$ min (22.8% of respondents); and amount of sleep in 24 h: $< 6.5$ h (16.0% of respondents); 6.5–7.5 h (42.4% of respondents), and $> 7.5$ h (39.3% of respondents).

The logistic regression involved two steps. First, univariate analyses were carried out to evaluate the relationship of a single personal or work factor with the outcome, without taking the other factors into consideration. All factors with a $P$-value $<$ 0.1 were considered for inclusion in the next step. Because the total number of female respondents was small ($N = 22$), analyses were not conducted on this group.

In the second step, logistic multiple regression analyses were calculated to determine the independent relationship of a factor with the outcome, while controlling for all other factors. Because the personal factors: getting enough sleep; waking refreshed; and ESS scores were likely to be highly correlated with the amount of sleep obtained in 24 h, only sleep duration was included in models.

To determine whether the same or different factors had an independent relationship to the outcome variable among Technical Certifying, Technical Noncertifying and Management and Technical Support staff, the same logistic multiple regression model was applied to each group.

## RESULTS

Of the 1279 employees who were sent questionnaires, 32 were unable to participate due to resignation, attending training, being offshore, or being on leave for illness/injury. A total of 984 SHoMe questionnaires and 968 sleep questionnaires were returned (overall response rate = 79%), with 966 respondents completing both questionnaires. Personal and work characteristics of respondents are described in **Table I**.

The median age of respondents was 42 yr (range = 18–69 yr), with the majority being male (97.5%). Age differed significantly across the three work types ($\chi^2$ (2) = 140.31, $P < 0.001$). Management and Technical Support staff were significantly older than both Technical Certifying staff ($P < 0.001$) and Technical Noncertifying staff ($P < 0.001$). Technical Certifying staff were significantly older than Technical Noncertifying staff ($P < 0.001$). Respondents spent, on average, 25 min (range = 3–115 min) commuting to work. There was no significant difference in commuting time between the three work types.

Respondents reported obtaining an average of 7.0 h (range = 4–16 h) of sleep in 24 h, with 41.1% stating they never or rarely got enough sleep. Of those who got $> 7.5$ h sleep in 24 h, 16.9% said they never or rarely got enough sleep, while 46.8% of those who got 6.5–7.5 h and 69.7% of those who got $< 6.5$ h of sleep in 24 h said they never or rarely got enough sleep [$\chi^2$ (2) = 125.54, $P < 0.001$]. There was no significant difference in getting enough sleep between those who worked permanent days, permanent nights, or rotating shifts [$\chi^2$ (2) = 1.81, $P = 0.414$] or according to the number of hours worked per week [$\chi^2$ (2) = 5.40, $P = 0.068$].

Almost half of respondents (46.2%) stated they never or rarely woke feeling refreshed, which was significantly associated with the usual amount of sleep in 24 h [$\chi^2$ (2) = 91.53, $P <$ 0.001]. The percentage of respondents who never or rarely woke feeling refreshed was 32.4% for those who got $> 7.5$ h, 57.2% for those who got 6.5–7.5 h and 78.6% for those who got $< 6.5$ h of sleep in 24 h. No significant differences were observed between type of shift [$\chi^2$ (2) = 1.159, $P = 0.564$] or number of hours worked per week [$\chi^2$ (2) = 5.260, $P = 0.071$] and waking feeling refreshed.

**Table I.** Comparison of Personal and Work Characteristics Between Technical Certifying Staff, Technical Noncertifying Staff, and Management and Technical Support Staff.

| CHARACTERISTIC | TECHNICAL CERTIFYING STAFF | TECHNICAL NONCERTIFYING STAFF | MANAGEMENT & TECHNICAL SUPPORT STAFF | *P*-VALUE |
|---|---|---|---|---|
| Age (yr)† | 44.0; 21–69 (339) | 36.0; 18–67 (479) | 50.0; 29–66 (133) | **<0.001*** |
| Commute (min)† | 25.0; 5–115 (340) | 25.0; 3–90 (486) | 25.0; 6–70 (134) | 0.610 |
| Sleep in 24 h (h)† | 7.0; 4.5–12 (331) | 7.0; 4–16 (481) | 7.0; 5–10 (133) | 0.373 |
| ESS score† | 7.0; 0–18 (329) | 7.0; 0–22 (474) | 6.0; 0–19 (133) | 0.266 |
| Sex‡: | | | | NA |
| Male (%) | 99.4 (339) | 98.0 (481) | 91.0 (122) | |
| Female (%) | 0.6 (2) | 2.0 (10) | 9.0 (12) | |
| Shift type‡: | | | | NA |
| Permanent days (%) | 17.5 (59) | 21.2 (103) | 60.3 (79) | |
| Permanent nights (%) | 3.6 (12) | 1.9 (9) | 3.8 (5) | |
| Rotating (%) | 78.9 (266) | 77.0 (374) | 35.9 (47) | |
| Work hours per week‡: | | | | 0.266 |
| <40 h (%) | 6.2 (21) | 13.9 (30) | 2.5 (10) | |
| 40–50 h (%) | 77.7 (265) | 52.3 (113) | 95.1 (387) | |
| >50 h (%)¶ | 14.7 (55) | 31.9 (73) | 2.5 (11) | |

† Data not normally distributed, therefore presented as median; range (*N*). Comparisons made using Kruskal-Wallis test. Post hoc analyses conducted using the Mann-Whitney test with Bonferroni correction.
* Management and Technical Support staff were significantly older than both Technical Certifying staff ($P < 0.001$) and Technical Noncertifying staff ($P < 0.001$). Technical Certifying staff were significantly older than Technical Noncertifying staff ($P < 0.001$).
‡ Data presented as percentage (*N*). Comparisons made using Pearson Chi-squared test.
¶ The number of participants who worked 60–70 h per week ($N = 5$ for Technical Certifying, $N = 4$ for Technical Noncertifying, and $N = 1$ for Management and Technical Support staff) and > 70 h per week ($N = 0$ for all work types) was too small for comparative analyses. Therefore, these data were combined with the number of participants who worked 50-60 h per week to create a single category.
NA, statistical comparison not possible between groups as the number of participants in some groups was too small ($N \leq 5$).

Nearly half (45.1%) of all respondents indicated that they had felt close to falling asleep while driving home from work in the preceding 12 mo. The amount of sleep in 24 h was significantly associated with feeling close to falling asleep behind the wheel [$\chi^2$ (2) = 11.277, $P = 0.003$]. The percentage of respondents who felt close to falling asleep was 37.5% for those who got > 7.5 h, 48.6% for those who got 6.5–7.5 h and 51.3% for those who got < 6.5 h of sleep in 24 h. Shift type was also significantly associated with feeling close to falling asleep behind the wheel [$\chi^2$ (2) = 34.72, $P < 0.001$]. The percentage of respondents who felt close to falling asleep while driving home was 51.0% for those working rotating shifts, 53.8% for those working permanent night shifts, and 29.2% for those working permanent day shifts. The number of work hours per week was also significantly associated with feeling close to falling asleep behind the wheel [$\chi^2$ (2) = 10.05, $P = 0.006$]. The percentage of respondents who felt close to falling asleep was 34.4% of those who work < 40 h, 44.5% of those who work 40–50 h, and 56.5% of those who work > 50 h per week.

The mean ESS score for all respondents was 7.4 (SD = 4.0). The number of participants with an ESS score > 10 (indicating excessive daytime sleepiness) was not significantly different between Technical Certifying staff (22.2%), Technical Noncertifying staff (19.5%) and Management and Technical Support staff [21.5%; $\chi^2$ (2) = 0.39, $P = 0.817$]. The number of hours worked per week was significantly related to having an ESS score > 10 [$\chi^2$ (2) = 9.51, $P = 0.009$]. One third (31%) of those who worked > 50 h per week, 16.9% of those who worked 40–50 h, and 16.9% who worked < 40 h per week had an ESS score > 10.

The majority of respondents (80.6%) said that they often or always got adequate breaks during their shift, and 91.1% said that their roster never or rarely changed unexpectedly. Nearly half (43.9%) said they often or always worked longer than their rostered shift, and 18.2% reported often or always getting called back to work on a scheduled day off. Compared to Aircraft Maintenance respondents, a significantly larger proportion of Line Maintenance respondents reported that they never or rarely got adequate breaks [14.8% vs. 42.3%; $\chi^2$ (1) = 63.96, $P < 0.001$] and that they often or always got called back to work [14.9% vs. 35.9%; $\chi^2$ (1) = 38.17, $P < 0.001$]. However, a significantly greater proportion of Aircraft Maintenance respondents reported often or always working longer than their rostered shift than Line Maintenance respondents [46.1% vs. 32.9%; $\chi^2$ (1) = 9.31, $P = 0.002$].

The majority of respondents (69.5%) reported they had never had any education on personal strategies for coping with the effects of shift work.

Nearly a quarter (22.3%, $N = 215$) of respondents indicated that they agreed/strongly agreed with the statement "During the last month I have made an error in my work due to tiredness," whereas 63.3% ($N = 611$) of respondents disagreed/strongly disagreed. The remaining respondents replied "not sure" (14.2%, $N = 137$) or did not respond (0.3%, $N = 3$).

In the univariate analyses (**Table II**), the amount of sleep obtained in 24 h had a significant relationship with making an error in work due to tiredness in all models, except for Technical Certifying Engineers. In all models, reporting never or rarely getting enough sleep, never or rarely waking feeling refreshed, and having excessive daytime sleepiness (ESS ≥ 10) was associated with making an error at work due to tiredness. However, in all models, age and length of commute had no significant relationship with the outcome.

Not getting adequate breaks during a shift had a significant relationship with making an error in work due to tiredness, but

**Table II.** Univariate Relationships Between Personal and Work Factors and Agreeing or Disagreeing with the Statement: "During the last month I have made an error in my work due to tiredness," for Technical Certifying Staff, Technical Noncertifying Staff, and Management and Technical Support Staff and for All Staff Together.

| | MALES ($N$ = 804) | | | TECH CERT ($N$ = 289) | | | TECH NON-CERT ($N$ = 415) | | | MANAGEMENT & SUPPORT ($N$ = 100) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FACTORS | DISAGREE (%) | AGREE (%) | *P*-VALUE* | DISAGREE (%) | AGREE (%) | *P*-VALUE* | DISAGREE (%) | AGREE (%) | *P*-VALUE* | DISAGREE (%) | AGREE (%) | *P*-VALUE* |
| Sleep in 24 h | | | | | | | | | | | | |
| <6.5 h | 64.2 | 35.8 | **0.006** | 67.6 | 32.4 | 0.51 | 65.3 | 34.7 | **0.013** | 45.5 | 54.5 | **0.009** |
| 6.5–7.5 h | 73.4 | 26.7 | | 76.1 | 23.9 | | 70.1 | 29.9 | | 77.5 | 22.5 | |
| >7.5 h | 76.9 | 21.1 | | 71.6 | 28.4 | | 81.4 | 18.6 | | 87.5 | 12.5 | |
| Getting enough sleep | | | | | | | | | | | | |
| Never/rarely | 65.3 | 34.7 | <**0.001** | 65.4 | 34.6 | **0.006** | 65.0 | 35.0 | **0.002** | 66.7 | 33.3 | **0.047** |
| Often/always | 80.1 | 19.9 | | 79.9 | 20.1 | | 79.0 | 21.0 | | 84.3 | 15.7 | |
| Waking refreshed | | | | | | | | | | | | |
| Never/rarely | 64.9 | 35.1 | <**0.001** | 66.0 | 34.0 | **0.002** | 65.0 | 35.0 | <**0.001** | 59.5 | 40.5 | <**0.001** |
| Often/always | 83.9 | 16.1 | | 82.2 | 17.8 | | 83.0 | 17.0 | | 90.5 | 9.5 | |
| ESS score | | | | | | | | | | | | |
| ≤10 | 78.3 | 21.7 | <**0.001** | 76.9 | 23.1 | **0.012** | 77.6 | 22.4 | **0.001** | 84.8 | 15.2 | **0.004** |
| >10 | 59.8 | 40.2 | | 60.7 | 39.3 | | 60.2 | 39.8 | | 55.0 | 45.0 | |
| Adequate breaks | | | | | | | | | | | | |
| Never/rarely | 67.1 | 32.9 | **0.018** | 65.7 | 34.3 | 0.088 | 65.6 | 34.4 | 0.108 | 73.3 | 26.7 | 0.36 |
| Often/always | 76.3 | 23.7 | | 76.1 | 23.9 | | 75.4 | 24.6 | | 81.4 | 18.6 | |
| Callback on days off | | | | | | | | | | | | |
| Never/rarely | 75.6 | 24.4 | 0.097 | 76.7 | 23.3 | **0.045** | 74.5 | 25.5 | 0.42 | 77.3 | 22.7 | 0.25 |
| Often/ always | 69.1 | 30.9 | | 64.9 | 35.1 | | 69.7 | 30.3 | | 91.7 | 8.3 | |
| Roster changes | | | | | | | | | | | | |
| Never/ rarely | 75.5 | 24.5 | **0.016** | 75.8 | 24.2 | **0.014** | 74.8 | 25.2 | 0.116 | 77.9 | 22.1 | 0.24 |
| Often/Always | 62.3 | 37.7 | | 52.2 | 47.8 | | 63.4 | 36.6 | | 100 | - | |

* *P*-values ≤ 0.05 are in bold type.

only in the model including all aircraft maintenance personnel. For Technical Certifying Engineers, often or always being called back to work on days off was associated with making an error in work due to tiredness. Often or always experiencing roster changes was associated with making an error in work due to tiredness in the model including all Aircraft Maintenance personnel, and in the model for Technical Certifying Engineers. Whereas, the number of work hours per week, type of shift (permanent days, permanent nights, rotating), type of work (aircraft maintenance, line maintenance), and working longer than the rostered shift had no significant relationship with the outcome at the univariate level in any of the models.

In multivariate models controlling for all personal and work related factors significant at the univariate level (**Table III**), and where responses from all participants were combined, there was no significant relationship between the amount of sleep obtained in 24 h and making an error in work due to tiredness. However, for Technical Noncertifying staff, the odds of making an error was significantly reduced for those who got > 7.5 h sleep in 24 h in comparison to those who got 6.5–7.5 h of sleep. Whereas, for Management and Technical Support staff, the odds of making an error in work due to tiredness was much greater for those who got < 6.5 h sleep in 24 h in comparison to those who got 6.5–7.5 h of sleep.

There was no significant relationship between getting adequate breaks during a shift, or getting called back to work on scheduled days off and making an error in work due to tiredness in any multivariate model. When the responses of all participants were combined, the odds of making an error in work due to tiredness was significantly higher for those respondents who said they often or always got unexpected roster changes compared to those who said they never or rarely got unexpected roster changes. This factor did not reach statistical significance in the separate models for each aircraft maintenance engineering group.

## DISCUSSION

The results of the present study indicate that in aircraft maintenance engineering, unexpected roster changes independently increase the odds of an error occurring due to tiredness. These findings are not unlike those seen in a study of UK aircraft maintenance engineers,[7] and in other workforces, such as Junior Doctors.[10] In the UK aircraft maintenance study, greater perceived risk on the night shift was associated with individuals receiving less notice of their shift schedule. Other factors were also related to perceived night-shift risk, such as control over start and finish times, length of the night shift, and the number of successive night shifts worked, which were not measured in the current study. Compared to the current study the outcome measure in the UK study was different, being a combined measure relating to alertness, the likelihood of making a mistake, and confidence in driving home.

It is not surprising that unexpected roster changes are related to an increased likelihood of making an error as such changes

**Table III.** Independent Relationships Between Personal and Work Factors and Making an Error in Work Due to Tiredness for Technical Certifying Staff, Technical Noncertifying Staff, and Management and Technical Support Staff and for All Staff Together (males, $N = 804$).

| WORK TYPE | FACTORS | | OR | 95% CI | *P*-VALUE* |
|---|---|---|---|---|---|
| Tech Certifying | Sleep in 24 h | <6.5 h | 1.30 | 0.57–2.97 | 0.532 |
| | | 6.5–7.5 h | 1.00 | | |
| | | >7.5 h | 1.27 | 0.71–2.27 | 0.430 |
| | Adequate breaks | Never/rarely | 1.00 | | |
| | | Often/always | 1.41 | 0.76–2.61 | 0.275 |
| | Callback on days off | Never/rarely | 1.00 | | |
| | | Often/always | 1.43 | 0.77–2.63 | 0.256 |
| | Roster changes | Never/rarely | 1.00 | | |
| | | Often/always | 2.47 | 0.99–6.21 | 0.054 |
| Tech Noncertifying | Sleep in 24 h | <6.5 h | 1.24 | 0.69–2.25 | 0.474 |
| | | 6.5–7.5 h | 1.00 | | |
| | | >7.5 h | 0.55 | 0.32–0.92 | **0.023** |
| | Adequate breaks | Never/rarely | 1.00 | | |
| | | Often/always | 1.44 | 0.78–2.65 | 0.241 |
| | Callback on days off | Never/rarely | 1.00 | | |
| | | Often/always | 1.11 | 0.61–2.02 | 0.737 |
| | Roster changes | Never/rarely | 1.00 | | |
| | | Often/always | 1.83 | 0.92–3.66 | 0.086 |
| Mgmt & Tech Supp | Sleep in 24 h | <6.5 h | 4.91 | 1.12–21.62 | **0.035** |
| | | 6.5–7.5 h | 1.00 | | |
| | | >7.5 h | 0.47 | 0.15–1.50 | 0.201 |
| | Adequate breaks | Never/rarely | 1.00 | | |
| | | Often/always | 1.79 | 0.58–5.57 | 0.314 |
| | Callback on days off | Never/rarely | 1.00 | | |
| | | Often/always | 0.15 | 0.01–1.57 | 0.113 |
| | Roster changes | Never/rarely | NA | NA | NA |
| | | Often/always | NA | NA | NA |
| All work types | Sleep in 24 h | <6.5 h | 1.47 | 0.94–2.31 | 0.090 |
| | | 6.5–7.5 h | 1.00 | | |
| | | >7.5 h | 0.75 | 0.52–1.08 | 0.122 |
| | Adequate breaks | Never/rarely | 1.00 | | |
| | | Often/always | 1.39 | 0.94–2.05 | 0.102 |
| | Callback on days off | Never/rarely | 1.00 | | |
| | | Often/always | 1.22 | 0.81–1.83 | 0.348 |
| | Roster changes | Never/rarely | 1.00 | | |
| | | Often/always | 1.78 | 1.05–3.02 | **0.034** |

* A factor with a *P*-value ≤ 0.05 has a significant independent relationship to the outcome.
OR, odds ratio.
NA, not applicable: unexpected roster changes was excluded from the model for Management and Technical Support staff, as no one in this group who reported often/always having unexpected roster changes made an error in work due to tiredness.

may impinge upon planned activities outside of work including sleep opportunities. In the present study other factors related to the arrangement and stability of work were not independently related to the odds of reporting an error at work due to tiredness but it should be noted that the fatigue-related risk is likely to be different depending on the engineer's role. For example, a large proportion of Line Maintenance engineers report never or rarely obtaining adequate breaks during their shifts and being called back to work on a scheduled day off, whereas Aircraft Maintenance engineers are more likely to work longer than their rostered shifts. This may indicate instances where safety margins are reduced within these respective roles.

Importantly, these findings can be used to form the basis of mitigation strategies and suggest that at a minimum, policies based on reducing the occurrence of unexpected roster changes would assist in reducing work errors caused by tiredness. Ensuring adequate breaks and reducing call backs on days off should also be considered for Line Maintenance and for Aircraft Maintenance the focus should be on decreasing the frequency with which individuals work longer than their rostered shift.

Another factor found to be independently related to increased odds of making an error at work due to tiredness was the usual amount of sleep individuals obtained in 24 h. When aircraft maintenance roles were divided into their respective positions, results indicated that usually getting less than 6.5 h sleep in 24 h greatly increased the odds of making an error at work due to tiredness for Management and Support staff. On the other hand, for Technical Noncertifying staff, getting more than 7.5 h sleep in 24 h had a protective function.

Managing fatigue risk in any work context is a responsibility shared by the employer and employee as fatigue is affected not only by the timing, duration and arrangement of work but also by an individual's choices and activities outside of work.[9] To enable an individual to take responsibility for themselves they must have an adequate understanding of the causes and consequences of fatigue. In the present context, almost three quarters of aircraft maintenance engineers reported having received no prior education on coping with the effects of shiftwork. The results of this study suggest that implementing education would be beneficial particularly around the personal risks associated with a reduced amount of sleep, which for this occupational group were also related to reporting feeling close to falling asleep at the wheel in the last 12 mo and rarely or never waking feeling refreshed.

Similarly, employers could utilize such information to ensure work factors do not unnecessarily impinge upon the safety of an individual outside of work. In the current study, nearly half (45%) of all respondents indicated that they had felt close to falling asleep while driving themselves home from work. This is a significant number of individuals at risk of harm but is lower than that reported by NZ junior doctors (66%).[10] A higher proportion of aircraft maintenance engineers reported feeling close to falling asleep at the wheel in the last 12 mo if they worked nights or rotating shifts, or worked more than 40 h per week. Some workplaces manage this risk by providing shiftworking individuals with the option of taking a taxi home from work (and back again) if they feel unsafe to drive.

The usual amount of sleep obtained by aircraft maintenance engineers in the presents study (7.0 h) is slightly shorter than that reported by aircraft maintenance engineers in a European organization (7.6 h) but average daytime sleepiness scores, as measured in both studies by the Epworth Sleepiness Scale, were slightly lower compared to the European engineers (7.4 vs. 7.8–8.1).[4] In the current study, 21% of aircraft engineering employees had excessive daytime sleepiness (as defined by an ESS score $>$ 10), which is higher than that found in surveys of the New Zealand general population (15%),[11] and tanker drivers (13%), but lower than locomotive engineers (Gander PH. Personal communication; 2000) and junior doctors (both 30%).[10] Similarly, the proportion of aircraft engineering employees reporting never or rarely getting enough sleep (41%) is greater than the proportion of the New Zealand population (37%), and of tanker drivers (31%) responding in the same way, but less than the proportion of locomotive engineers (59%), and junior doctors (46%). Shiftwork is expected to pose challenges for sleep and daytime sleepiness, and it appears this is also the case for aircraft maintenance engineers who in general sleep less and are sleepier than the general population but are not as adversely affected as some other shiftworking populations.

A limitation of this study is that only retrospective, subjective data were collected which may have influenced the recall of error. In addition, only a single maintenance engineering organization participated, therefore the generalizability to other aircraft maintenance settings needs to be carefully considered. However, the high response rate (79%) is a significant strength and data were obtained from different geographical locations and encompassed Line and Aircraft Maintenance personnel in different roles (Technical Certifying staff, Technical Noncertifying staff and Management and Technical Support staff), thus providing a broad picture of the potential issues across aircraft maintenance engineering.

This survey of nearly 1000 personnel working in aircraft maintenance engineering indicates the importance of considering the stability and predictability of work patterns in minimizing the risk of errors occurring due to tiredness. It also points toward the need for a shared understanding of fatigue related issues and providing the workforce with sufficient knowledge so that they can manage their own fatigue by obtaining sufficient sleep away from work.

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