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Duty hours and incidents in flight among commercial airline pilots

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Introduction. Working long duty hours has often been associated with increased risk of incidents and accidents in transport industries. Despite this, information regarding the intermediate relationship between duty hours and incident risk is limited. This study aimed to test a work hours/incident model to identify the interplay of factors contributing to incidents within the aviation industry. *Methods*. Nine hundred and fifty-four European-registered commercial airline pilots completed a 30-item survey investigating self-report attitudes and experiences of fatigue. Path analysis was used to test the proposed model. *Results*. The fit indices indicated this to be a good fit model ($\chi^2 = 11.066$, $df = 5$, $p = 0.05$; Comparative Fit Index = 0.991; Normed Fit Index = 0.984; Tucker–Lewis Index = 0.962; Root Mean Square of Approximation = 0.036). Highly significant relationships were identified between duty hours and sleep disturbance ($r = 0.18$, $p < 0.001$), sleep disturbance and fatigue in the cockpit ($r = 0.40$, $p < 0.001$), and fatigue in the cockpit and microsleeps in the cockpit ($r = 0.43$, $p < 0.001$). *Discussion*. A critical pathway from duty hours through to self-reported incidents in flight was identified. Further investigation employing both objective and subjective measures of sleep and fatigue is needed.

Keywords: sleep; fatigue; flight incidents; path analysis

1. Introduction

A majority of accidents or adverse events within the transport industry have been attributed to human rather than technical errors.[1] Several extensive studies have been published indicating that long working hours (more than 50 h) are associated with an increased risk of incidents and accidents.[2–4] Similar findings have been demonstrated within other sectors of the transport industry, specifically the maritime,[5] railway [6] and road domains.[7,8] Existing research would suggest that increasing hours on duty may be associated with an increased likelihood of incidents.

Numerous large-scale events have demonstrated the often catastrophic duty hours/incident/accident relationship within the aviation industry, such as the 2004 Corporate Airlines Flight 5966 crash [9] and the 1997 Korean Airline Flight 801 incident.[10] Whilst existing studies regularly highlight the relationship between working hours and incident or accident risk, this research often fails to explore the interplay of key factors which may be causative and/or contributory. To date, only one previous study has attempted to investigate the intermediate relationship between long work hours and associated accident risk factors. Schuster and Rhodes [11] proposed a theoretical model of overtime and long work hours, and risk of workplace accidents. This model proposes that overtime and long work hours affect the risk of workplace accidents by triggering various intermediary conditions in affected workers, such as fatigue, stress and drowsiness. The pathway linking a demanding work schedule to the intermediary condition, and in turn to a workplace accident, can be mediated by numerous individual and environmental factors, including personal characteristics (e.g., age, gender, health status, job experience), job factors (e.g., intensity of work, exposure to hazards) and organisational factors (e.g., overtime policy, supervision) (see Figure 1). Dembe et al. [3] investigated the impact of overtime and long work hours (more than 8 h per day) on occupational injuries and illnesses employing Schuster and Rhodes' [11] theoretical model as its conceptual basis. According to the authors, the findings of this study supported the hypothesis that long working hours indirectly influence workplace accidents through a causal process, by inducing fatigue or stress in affected workers.[3] However, their findings also coincide with alternative hypotheses and therefore cannot be certain of the existence of a causal connection.

Taking into consideration Schuster and Rhodes' [11] theoretical model, a further in-depth investigation in to the work hours/incidents literature was conducted by the authors of the present study. Emerging factors were identified as increasing hours spent on duty, sleep disturbance, fatigue, lapses in attention and errors. Further exploration of these variables led to the identification of specific pathways: (a) increasing hours spent on duty have been found

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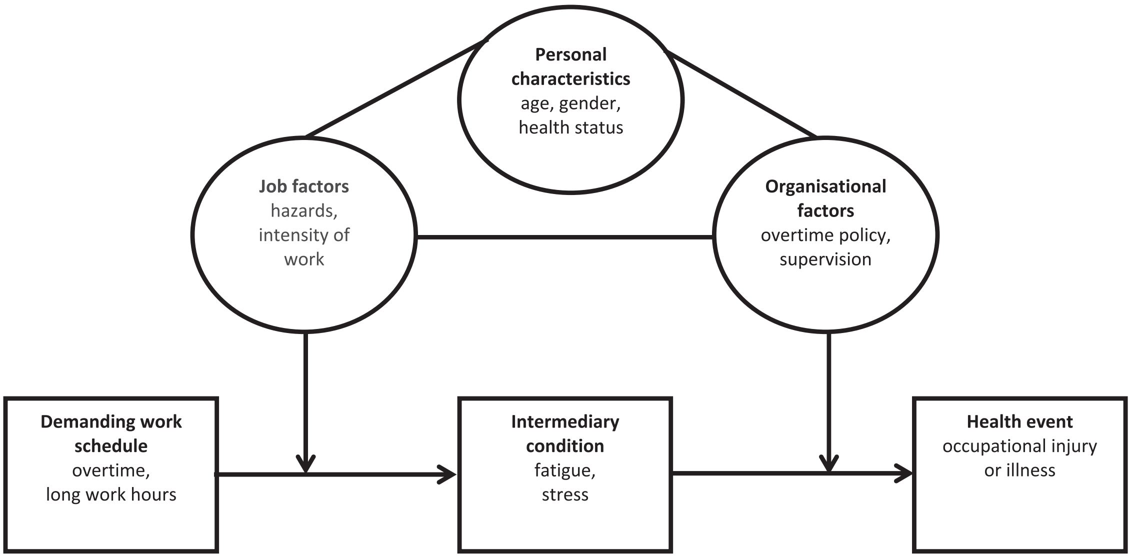

Figure 1. Conceptual model of the relationship between demanding work schedules and occupational injuries and illnesses (adapted from Schuster and Rhodes [11]).

to result in sleep loss and contribute to fatigue;[12] (b) prolonged working hours, long duration of wakefulness and inadequate sleep are identified as some of the major causes of fatigue and can result in a homeostatic drive to sleep;[13] (c) fatigue manifests itself in various ways such as by lapses in attention;[14] (d) momentary lapses in attention, regardless of how brief they are, can cause impairments in performance;[15,16] (e) according to Reason's [17] Accident Causation Model, an accident often arises due to multiple independent events or errors which in turn lead to an accident. Table 1 contains an overview of the published literature highlighting the relationship between each of these variables.

Within the aviation industry, there is great concern that pilot schedules can lead to fatigue and increase the likelihood of flight incidents and accidents.[20] An incident is defined as 'an occurrence, other than an accident, associated with the operation of an aircraft which affects or could affect the safety of operation'.[39, p10] This study is concerned with 'incidents', as opposed to accidents, exclusively. The aim of this study was to evaluate a general work hours/incident model with the intention that a more in-depth comprehensive understanding of the association between potential interplaying factors in the work hours/incidents relationship will aid in providing a basis for further investigation and analysis to this complex relationship. Such research will in turn inform and assist in the identification of potential countermeasures to reduce accident risk and therefore aid in identifying safe and effective evidence-based duty hours legislation. This study hypothesised that major European-registered commercial airline pilots who spend longer hours on duty in a typical week would experience greater disruption to their normal sleeping patterns, have greater experiences of fatigue in the cockpit, experience more lapses in attention in the cockpit, which in turn would be associated with making more errors in flight and ultimately more incidents in flight.

Table 1. Overview of previously published findings highlighting the relationships between each pair of variables.

Variable 1	Variable 2	Published research
Duty hours	Sleep disturbance	[12,18,19]
Duty hours	Fatigue	[20–22]
Sleep disturbance	Fatigue	[6,23–25]
Sleep disturbance	Lapses in attention	[26,27]
Fatigue	Lapses in attention	[14,28,29]
Fatigue	Error	[30–33]
Fatigue	Incident	[5,34,35]
Lapses in attention	Error	[26,28,36,37]
Lapses in attention	Incident	[26,37]
Error	Incident	[17,38]

2. Methods

2.1. Participants

Two thousand, one hundred and eighty-six email addresses of European-registered commercial airline pilots, all flying with airlines registered from the same European state, were obtainable and forwarded a link to an anonymous online survey. Details of the background and purpose of the study were also provided as well as instructions on how to complete the survey. Prior to survey distribution, ethical approval was granted by Dublin City University Ethical Committee (DCU REC/2012/155).

2.2. Survey development

Eight European Cockpit Association (ECA) members conducted similar surveys to investigate attitudes and experiences of fatigue among their pilots, three of which were obtainable prior to this study. Following a comprehensive review of the existing scientific literature, analysis of the three other unpublished European pilot fatigue surveys (conducted by the Norwegian Airline Pilots' Association,[40] the Danish Airline Pilots' Association [41] and the Swedish Airline Pilots' Association [42]) and focus groups with experienced professional pilots who fly for European-registered airlines, an initial 30-item survey was created using the web survey development cloud based company, Survey Monkey®. The survey addressed eight main topics: Demographics, Captain's Discretion, Personal Health, Overall Attitudes and Opinions to Regulations and Associated Bodies, Experiences of Lapses in Attention, Errors and Incidents, Attitude to and Experiences of Fatigue and Duty Periods. For the purpose of this study, only those questions pertaining to demographics and the latter four topics were addressed.

The survey was then reviewed by the research team and separately by two experienced commercial airline pilots to aid in the identification of any ambiguities in the questions. These individuals were also asked to give their opinions on the overall content of each item as a determination of 'face validity'. The questions were then amended accordingly. Consequently, the survey was sent to four experienced professionals (2 airline captains, 1 university professor and 1 university lecturer), who were involved in the development of the other European pilot fatigue surveys, to gather further information regarding the survey format, layout and content. This process served as a measure of 'content validity'. This information was analysed and appropriate alterations were implemented. Following this, 10 pilots, who currently fly with European-registered airlines, were randomly selected and asked to perform the online survey. They were also asked their opinions on the language used, duration, layout and overall survey content. Following this, the final amendments to the survey were implemented in preparation for distribution to the study participants.

This 30-item survey contains time-bound questions (i.e., 'within the last 3 years'). Note: at the time of survey distribution, current flight time limitations (FTLs) were those set out under the European Air Operations (EU-OPS) Subpart Q which came into effect in July 2008. Therefore, all questions in this survey referred to the period from July 2008 to November 2012. Furthermore, 'typical duty hours' refers to the number of hours spent on duty in a typical week, and was stated to the participants as so. (Please see the European Aviation Safety Agency (EASA) [43] for more information pertaining to the rules on Flight and Duty Time Limitations and rest requirements for commercial air transport with aeroplanes.)

2.3. *Path analysis and structural equation modelling (SEM)*

This study employed path analysis to test this model (outlined in Figure 2) using AMOS 21. Various fit indices were employed to determine how well the proposed model fits the sample data. Initially, χ^2 statistics were used to determine the measure of fit between the sample covariance and fitted covariance matrices.[44] A statistically insignificant value of χ^2 indicates a good fit with proposed model data. Furthermore, the Comparative Fit Index (CFI), the Normed Fit Index (NFI) and the Tucker–Lewis Index (TLI) (also known as the Non-Normed Fit Index (NNFI)) were additional values used to assess the appropriateness of the proposed model to the sample data. For these indices, values in the 0.90 range and above are indicative of optimal

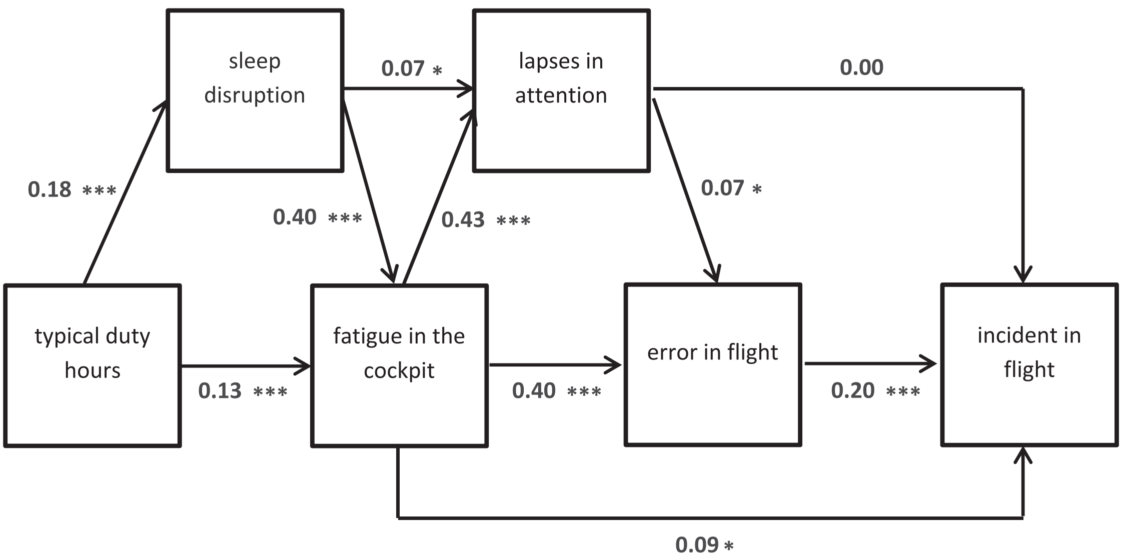

Figure 2. Path diagram of proposed model with relationships.
Note: Standardised estimate values are reported. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

fit.[45] Additionally, the Root Mean Square of Approximation (RMSEA) is another fit index which considers the error of approximation in the population.[44] Values less than 0.05 are indicative of good fit, values of 0.08 or less are indicative of reasonable errors of estimation in the population whilst values of 0.08–0.10 are indicative of mediocre fit.[46]

2.4. *Study overview*

Participants were emailed a link to the survey which they could anonymously complete online. Each pilot was sent a unique link direct to their personal email address which could be used only once in order to avoid completion of the survey by non-pilots and prevent replication. An 'opt-out' option was included for those who did not wish to take part in the survey. Reminder emails were sent every week. The survey remained live for 7.5 weeks, until survey uptake plateaued.

3. Results

3.1. *Survey distribution and completion*

Two thousand, one hundred and eighty-six surveys were distributed via email of which 954 were fully completed. Only those surveys that were fully completed were considered for analysis. This equated to a 43.6% response rate. This figure is representative of 29.8% of the overall population of commercial airline pilots from the European state used in this study, at the time the survey was completed.

3.2. *Demographic data*

In the present sample, 94.9% ($n = 905$) were male while 5.1% ($n = 49$) were female (Table 2). A majority of those were aged 26–35 years (42.0%, $n = 401$). Just over half of those surveyed were captains (51.8%, $n = 494$)

Table 2. Descriptive and demographic data.

Gender	Male = 94.9% ($n = 905$)
	Female = 5.1% ($n = 49$)
Age (years)	≤25 = 12.0% ($n = 115$)
	26–35 = 42.0% ($n = 401$)
	36–45 = 29.0% ($n = 277$)
	46–55 = 13.7% ($n = 131$)
	56–65 = 2.5% ($n = 24$)
	Prefer not to say = 0.8% ($n = 6$)
Position	Captain = 51.8% ($n = 494$)
	First/second officer = 46.9% ($n = 447$)
	Prefer not to say = 1.3% ($n = 13$)
Employment	Full-time = 97.0% ($n = 925$)
	Part-time = 3.0% ($n = 29$)
Type of employment	Permanent = 54.1% ($n = 516$)
	Contract = 45.5% ($n = 434$)
	Prefer not to say = 0.4% ($n = 4$)

Note: Total sample size, $n = 954$.

while 46.9% ($n = 447$) were first officers. In terms of employment status, 54.1% ($n = 516$) were permanent while 45.5% ($n = 434$) were on a fixed-term contract. A total of 97.0% ($n = 925$) worked full-time with 3.0% ($n = 29$) working part-time.

3.3. *Path analysis findings*

The path analysis findings are pictorially represented in Figure 2.

Number of hours spent on duty in a typical week was positively associated with disruption to normal sleeping patterns ($r = 0.18$, $p < 0.000$) and was positively associated with experiences of fatigue in the cockpit ($r = 0.13$, $p < 0.000$). Therefore, based on this survey's findings, European-registered airline pilots who spend longer hours on duty in a typical week, are more likely to experience greater disruption to their normal sleeping patterns and have more regular experiences of fatigue in the cockpit.

Disruption to normal sleeping patterns was also positively correlated with experiences of fatigue in the cockpit ($r = 0.40$, $p < 0.000$). Therefore, those who experience greater disruption to their normal sleeping patterns were found to have more regular experiences of fatigue in the cockpit. Although found to be significant, disruption to normal sleeping patterns was not considered to be correlated with lapses in attention in the cockpit due to a small r value ($r = 0.07$, $p < 0.05$).

Experiences of fatigue in the cockpit was positively associated with lapses in attention in the cockpit ($r = 0.43$, $p < 0.000$) and with self-reported errors in flight ($r = 0.40$, $p < 0.000$). Therefore, European-registered airline pilots who more regularly experience feelings of fatigue in the cockpit, are more likely to have lapses in attention in the cockpit and are more likely to make errors in flight. Again, although found to be significant, experiences of fatigue in the cockpit were not considered to be correlated with self-reported incidents in flight due to a small r value ($r = 0.09$, $p < 0.05$).

Whilst lapses in attention in the cockpit was significantly associated with self-reported errors in flight ($r = 0.07$, $p < 0.05$), a small r value precludes this from being a significant contributor to the model. Lapses in attention in the cockpit was not significantly correlated with self-reported incidents in flight.

Self-reported errors in flight were found to be positively associated with self-reported incidents in flight ($r = 0.20$, $p < 0.000$) indicating that those who make more errors in flight typically report more incidents in the cockpit.

The fit indices showed that this was a good fit model ($\chi^2 = 11.066$, $df = 5$, $p = 0.050$). Therefore, it indicates that the proposed model fits the data well. The values for the CFI, NFI and TLI were 0.991, 0.984 and 0.962, respectively. The TLI and NFI values indicate that the measured variables are correlated while the CFI indicates the

Table 3. Revised modification indices.

Revised modification index	Value
Comparative Fit Index (CFI)	0.983
Normative Fit Index (NFI)	0.973
Tucker–Lewis Index (TLI)	0.956
Root Mean Square of Approximation (RMSEA)	0.038

same taking into account the sample size.[47] The RMSEA was 0.036, indicative of good fit (Table 3). Therefore, this value implies that the proposed model fits the population's covariance matrix.[44]

3.4. *Revised path analysis*

The path analysis was re-run removing the three non-/low significant relationships between 'sleep disturbance and lapses in attention in the cockpit', 'lapses in attention in the cockpit and self-reported errors in flight' and 'lapses in attention in the cockpit and self-reported incidents in flight'. The purpose of this was to identify if the removal of such pathways would contribute to a better model fit. The fit indices indicated that the model still retained relatively good fit ($\chi^2 = 19.359$, $df = 5$, $p = 0.012$). The values for the CFI, NFI and TLI were 0.983, 0.973 and 0.956, respectively, while the RMSEA was 0.038. Whilst the revised model still retained a good model fit, the original model proved a better fit.

4. Discussion

The aim of the present study was to test a model of duty hours and self-reported incidents in flight in European-registered commercial airline pilots. It is based on the hypothesis that commercial airline pilots who spend longer hours on duty in a typical week: experience greater disruption to their normal sleeping patterns; have more regular experiences of fatigue in the cockpit; have more regular lapses in attention in the cockpit; make more errors in flight and ultimately have more incidents in flight. Strong support was found for the proposed relationships and overall model.

The model presented here proposes that there is a positive correlation between hours on duty and probability of an incident in flight. According to Folkard et al.,[48] the risk of an accident exponentially increases with time on shift. It was found that relative to 8-h shifts, there is a 13% increased risk of an accident on 10-h shifts while 12-h shifts are associated with a 27% increased risk of an accident. Additionally, Goode [20] analysed human-factor-related accidents and pilot work patterns from 1978 to 1999. Findings concluded that the percentage of accidents is greater for more lengthy duty periods than the percentage of lengthy duty periods in the all-pilot group. Goode [20] found that pilots spend approximately 10% of their working hours in the 10th or greater hour of a given duty period. The study further noted that it is in this same period that 20% of aviation accidents occur. Similar to this study's findings, the general consensus in the literature suggests that as hours on duty increases, there is an increased likelihood of an incident or accident.

Time spent on duty was also found to have a positive relationship with sleep disturbance. Based on the existing body of research, it is broadly accepted that long work hours have a negative effect on sleep.[12,18] In a study investigating sleeping patterns in the general population, Ribet and Derriennic [19] examined more than 21,000 adults in France, using a sleep disturbance index and logistic regression analysis. It was found that a long working week (>48 h) was one of the main risk factors for sleep disturbance when controlling for age and gender. Hours spent on duty was also found to have a positive relationship with experiences of fatigue in the cockpit. Goode [20] found that as duty hours increase, there is a relatively constant increase in fatigue. However, according to Siegrist [49] and van der Hulst and Geurts,[50] when rewards of working, such as payment, appreciation by peers and co-workers, are perceived to be high, long working hours do not lead to fatigue. Although the present study was not designed to measure the specific number of hours pilots spent on duty, the results indicate that those pilots who are spending longer hours on duty, have greater disturbance to their regular sleeping patterns and have more regular experiences of fatigue in the cockpit.

Sleep disturbance was found to have a strong relationship with experiences of fatigue in the cockpit. Serious real-life catastrophic events have demonstrated this relationship. According to the National Transportation Safety Board (NTSB),[51] the *Exxon Valdez* accident in 1989 occurred as a result of fatigue due to reduced sleep and extended work hours. Neville et al. [52] examined airline crews exposed to shift work and time zone crossing during Desert Storm. The authors concluded that recent sleep and flight histories were correlated with high subjective fatigue levels. Sleep disturbance, whilst found to be significant, surprisingly demonstrated a very weak relationship with lapses of attention in the cockpit. Akerstedt et al. [26] conducted an open cohort study with repeated national cross-sectional surveys comprising of a systematic sample of the Swedish population between 16 and 84 years. Overtime work was not found to result in significant sleep disruption. According to the authors, extreme levels of overtime work may be needed in order to observe effects on sleep. They also proposed that most overtime is voluntary which may thwart adverse sleep effects through selection of those most tolerant of overtime work.

Fatigue is an insidious state which manifests itself in various different ways such as reductions in vigilance, impairments in judgement and an increase in reaction time.[53] In the present study, experiences of fatigue in the cockpit were found to be positively associated with lapses in attention in the cockpit. According to Caldwell,[9] fatigue results in a reduction in an aviator's ability to pay attention to flight instruments, crew coordination, radio communications and navigational tasks. The present study also found highly significant direct and positive relationships between experiences of fatigue in the cockpit and self-reported errors in flight, and self-reported incidents in flight. A growing body of research indicates that greater levels of fatigue are associated with an increased probability of errors.[30] According to Akhtar and Utne,[5] fatigued individuals are less able to handle complex interactions and foresee the consequences of their actions, increasing the likelihood of an accident. Considerable evidence exists highlighting the possible contributory effect of fatigue to serious accidents in industrial operations, nuclear power plants and virtually all modes of transport (rail, marine, aviation, motorway).[54,55] However, a detailed understanding of the relationship between increased fatigue and the risk of accidents has yet to be established.[23] The present study has aided in highlighting a potential pathway from disturbed sleep, due to increasing hours on duty, through to fatigue and ultimately to errors and incidents in flight.

Attention is essential in order to process incoming information, focus on relevant cues for the task at hand and actively disregard distractors to the task goal.[56] Landrigan et al. [57] examined medical interns on call and found that reducing the total work week from 80 to 60 h per week with a maximum shift of 16 h (as opposed to 24–36 h) resulted in a 50% reduction in serious errors. It was concluded that the protection of sleep and the reduction of total hours was responsible for the effects. According to Dinges and Powell,[36] tasks which require sustained attention, such as monitoring aircraft systems and flight progress, can cause significant issues for already fatigued individuals. Surprisingly, lapses in attention in the cockpit was found to have a very small relationship with self-reported errors in flight whilst it was not found to have any relationship with self-reported incidents in flight in the present study. One potential explanation for this finding is the possibility of under-reporting errors and incidents. According to Webb et al. [58] and Sinclair and Tetrick,[59] individuals often under-report accidents due to factors such as fear of reprisals or loss of benefits. Fear among the pilots of potential exposure of results may have deterred participants from admitting error or incidents in flight. Self-reported error in flight was also found to have a positive relationship with self-reported incidents in flight in the present study. According to Cacciabue,[60] accidents rarely occur due to a single system failure or deliberate human decisions. They usually occur when seemingly small, unimportant events and critical human errors combine.

The overall model in the present study was found to be a very good fit indicating a strong proposed pathway between duty hours and incidents in flight. Although various studies have demonstrated different segments of the proposed pathways,[9,31] none have demonstrated a complete model. Findings from field study research within the medical and aviation industries, by Barger et al. [61] and Goode,[20] demonstrated that augmented workloads, especially in combination with disturbed sleep and fatigue, can result in significant performance errors, which in turn, can result in incidents and/or accidents. The model identified in the present study provides a strong basis on which further investigation in to the interplay of fatiguing factors influencing flight safety can be conducted.

5. Limitations

There are several limitations to the current study. Firstly, observations are based upon self-reported rather than objective measures. Self-reported experiences and ratings of variables may be influenced by social desirability as well as cognitive difficulties associated with recall.[62] Furthermore, this study did not control for variability of pilot scheduling at the time of survey completion.

6. Future recommendations

Sleep and fatigue appear to be at the epitome of the work hours/incident model. Further exploration, investigating both objective and subjective components of sleep and fatigue and their associated impact on flight safety is needed in order to better understand this complex and potentially catastrophic relationship. Furthermore, numerous additional factors exist which are proposed to influence the work hours/incident relationship such as circadian factors, stress, gender and age [11,63] and as such should be included in further investigations.

7. Conclusion

The primary reason for conducting this research was to identify a basis conceptual model consisting of some of the core variables found to influence the work hours/incident relationship. Establishing this foundation provides a base on which to further investigate the intricate and complex relationship between duty hours and incidents in flight. The findings concluded that European-registered commercial airline pilots who spend longer hours on duty in a typical week: experience greater disruption to their normal sleeping patterns; have more regular experiences of fatigue in the cockpit; have more regular experiences of lapses in attention in the cockpit; make more errors in flight and ultimately have more incidents in flight. Whilst the proposed model provides a sound conceptual basis, further investigation, considering both objective and subjective measures of sleep and fatigue within an aviation environment as well as additional variables proposed to influence the duty hours/incident relationship is needed.

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