Sleep Loss and Fatigue Among Commercial Airline Pilots

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Doctor of Philosophy

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Declaration

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Definition of Terms

Airline Pilot Core competencies: A group of related behaviours, based on job requirements, which describe how to effectively perform a job and what proficient performance looks like (ICAO Manual, 2013).

Circadian Rhythm: Any biological process which contains an endogenous, entrainable oscillation of approximately 24 hours (typically 24.25 hours).

Commercial Airline Pilot: An airline pilot licensed to transport passengers and goods.

Confidence Interval: A range of values so defined that there is a specified probability that the value of a parameter lies within it.

Flight and Duty Time Limitations (FTL's): These are a legally binding minimum set of safety rules, set out by EASA, and are intended to prevent pilot fatigue across Europe. They are contained within the EU-OPS – subpart Q.

Duty Period: Duty time is the full period that a pilot is on duty, from the moment they report to duty to the moment they are free of all duties. The duty time is made up of the 'flight duty period' and any subsequent duty time before the off-duty period.

Error: An action or inaction by the flight crew that leads to deviations from organisational or flight intentions or expectations (EASA, 2009).

European Aviation Safety Agency (EASA): EASA is an agency of the European Union (EU) with regulatory and executive tasks in the field of civilian aviation safety. Its mission is to promote the highest common standards of safety and environmental protection in civil aviation. The Agency develops common safety and environmental rules at the European level.

European regulations on Air Operations (EU-OPS) – Subpart Q: This contains the current flight and duty time limitations (FTL's) set out by the European Aviation Safety Agency (EASA).

Fatigue: "A condition characterised by increased discomfort with lessened capacity for work, reduced efficiency of accomplishment, loss of power or capacity to respond to stimulation, and is usually accompanied by a feeling of weariness and tiredness" (Federal Aviation Administration, 2007, pp. 1)

Flight Time: This refers to the moment of duty time when the aircraft first moves under its own power for the purpose of taking-off, until the moment at which it comes to rest after landing, whereas the 'flight duty period' is the part of the duty period that includes both flight time, pre- and post-flight duties, and positioning or other duties at the beginning of the duty period.

Holding Pattern: Manoeuvre consisting of making the aircraft turn around the aerodrome at an assigned altitude, while awaiting further Air Traffic Controller (ATC) instructions.

Incident: An occurrence…associated with the operation of an aircraft which affects or could affect the safety of operation (ICAO Annex 13).

International Civil Aviation Organisation (ICAO): The ICAO is a United Nations specialised agency, established in 1944 to manage the administration and governance of the Convention on International Civil Aviation.

International Civil Aviation Organisation (ICAO) Manual of Evidence-Based Training: This manual is intended to provide guidance to Civil Aviation Authorities, operators and approved training organisations in the recurrent assessment and training of pilots (ICAO Manual, 2013).

Long-Haul Flights: Long-haul operations last 6+ hours usually with one or two sectors maximum.

Medium-/Short-Haul Flights: Medium-/short-haul operations are typically classified as being less than 6 hours in duration with several sectors in a single duty period.

Microsleep Event: A microsleep event is an unexpected brief episode of sleep which lasts anything between 1 to 30 seconds and occurs in the midst of ongoing wakeful activity (Moore-Ede et al., 2004).

Moebus Report: A scientific and medical evaluation of some of the Flight Time Limitation provisions contained in Subpart Q of the EU OPS (Moebus Aviation, 2008).

National Transportation Safety Board (NTSB): A United States government organisation in charge of investigating in the case of an accident.

Shift Work: Typically, shift work refers to work schedules in which the 24 hours are divided into roughly similar sizes and three or more teams are utilised to provide 24 hour coverage. Teams can remain permanent or alternate between (i) early morning, (ii) afternoon or (iii) night shifts.

Sleep Deprivation: Sleep deprivation is the condition of having insufficient sleep. It refers to a complete lack of sleep across a certain period of time or a shorter than optimal sleep period (Orzel-Gryglewska, 2010). It can be acute, which generally refers to being kept awake continuously for 24 – 72 hours, or chronic in nature, in which sleep is restricted over the course of several consecutive nights (Minkle, 2010).

Standard Deviation: A quantity calculated to indicate the extent of deviation for a group as a whole.

List of Abbreviations

ADSB = Auditory Digit Span Backward

ADSF = Auditory Digit Span Forward

AH = Auditory Hits

AIRSIM = Avionics Integration Research SIMulator

APM = Average Pitch Magnitude

ARM = Average Roll Magnitude

ATM = Average Throttle Magnitude

CAA = Civil Aviation Authority

CANTAB = Cambridge Neuropsychological Test Automated Battery

CCAR = China Civil Aviation Regulations

CFI = Comparative Fit Index

CI = Confidence Interval

CR-FC = Correct Responses to mid-flight Fuel Calculations

CR-MC = Correct Responses to aviation-specific Mathematical Calculations

DALPA = Danish Airline Pilots Association

DCU = Dublin City University

EASA = European Aviation Safety Agency

ECA = European Cockpit Association

EPST = European Pilot Selection & Training

EU-OPS = European Regulations on Air Operations

FAA = Federal Aviation Administration

FRMS = Fatigue Risk Management System

FSS = Fatigue Severity Scale

FTL - Flight Time Limitation

GPB = Grooved Pegboard

HDEV = Horizontal Deviation

HSE = Health and Safety Executive

ICAO = International Civil Aviation Organisation

NFI = Normed Fit Index

NIN = Netherlands Institute for Neuroscience

NLR = National Aerospace Laboratory

NNFI = Non-Normed Fit Index

Non-REM = Non-Rapid Eye Movement

NRK = Norwegian Airline Pilots Association

NTSB = National Transport Safety Board

OR = Odds Ratio

PFC = Prefrontal Cortex

POMS = Profile of Mood States

PVT = Psychomotor Vigilance Task

PVT-MLA = Psychomotor Vigilance Task-Lapses in Attention

PVT-MRT = Psychomotor Vigilance Task-Mean Reaction Time

RMSEA = Root Mean Square Errors

RMSEA = Root Mean Square of Approximation

RVP = Rapid Visual Information Processing Task

SA = Situation Awareness questions

SART = Situation Awareness Rating Technique

SCN = Suprachiasmatic Nucleus

SCWT = Stroop Colour and Word Test

SD = Standard Deviation

SE = Standard Error

SPC = Samn Perelli Crew Status Check

SWALPA = Swedish Airline Pilots Association

TAS = Total Airspeed

TCAS = Traffic Avoidance Collision System

TLI = Tucker=Lewis Index

TMD = Total Mood Disturbance

TT-FC = Time Taken to complete mid-flight Fuel Calculations

TT-MC = Time Taken to complete aviation-specific Mathematical Calculations

VDEV = Vertical Deviation

VH = Visual Hits

Abstract

Sleep Loss and Fatigue Among Commercial Airline Pilots

Anna Donnla O'Hagan

Today's flight operations work on a pressurised 24/7 timetable as a result of the unrelenting escalation in international long-haul, short-haul, regional and overnight flights within commercial aviation. Air traffic around the world has doubled every 10 years for the last 30 years. Whilst there have been considerable advancements in aviation technology and operational demands, the human operators need for sleep remains. Commercial airline pilots are presently highly suspectible to sleep loss and fatigue due to these demanding, round-the-clock requirements. Whilst flight and duty time limitation regulations are in place to prevent pilot fatigue, they are not based on sound scientific evidence regarding their ability to do so. Furthermore, various European-based investigations have reported very high levels of sleep disruption and fatigue in European cockpits. Therefore, this study aimed to examine the influence of sleep deprivation and associated fatigue on incidents in flight and mental health and to investigate its effects on performance in commercial airline pilots. Firstly, this research found a critical pathway from duty hours through to self-reported incidents in flight with sleep disruption and feelings of fatigue in the cockpit found to be key factors contributing to this pathway (Study 1). This research also found very high incidences of self-reported sleep disturbance, feelings of fatigue in the cockpit, and consequential errors and incidents in flight as a result of fatigue. Further to this, self-reported sleep disruption and feelings of fatigue were also found to significantly influence pilots' self-reported perceived depression or anxiety with those who reported higher incidences of sleep disturbance and fatigue being more likely to report feeling depressed or anxious (Study 2). Additionally, 24 hours' sleep deprivation and subsequent fatigue was found to significantly impair mood and airline pilot core competencies, specifically cognitive flexibility, hand-eye coordination, multi-tasking ability, sustained attention, problem-solving, situation awareness and perceived workload with significant impairments becoming evident following 20 hours of continuous wakefulness (Study 3 & 4). Flying performance was not significantly impaired. Sleep disruption and fatigue is a highly serious and prevalent problem in European cockpits. It negatively impacts flight safety and pilot mental health and well-being. Further investigation in to the current flight and duty time limitation regulations as well as in to potential measures which could act as early detection and warning indicators of declining performance, as a result of sleep loss and fatigue, would enhance flight safety and promote pilot mental health and well-being.

Chapter 1

Introduction

1.1 Introduction

Today's flight operations require commercial airline pilots to consistently perform in demanding, complex and stressful environments on a 24/7 timetable (Caldwell et al., 2009). Various parameters impact pilot performance (i.e., noise, vibrations, nutrition, drug use) of which, sleep is one (Lindgren, Andersson & Norbäck, 2006). Sleep is an essential biological phase within the daily life-cycle without which life would not continue (Krueger et al., 2016). Sleep loss may occur as a result of various aspects such as circadian, pharmacologic, emotional or psychological factors. According to Orzel-Gryglewska (2010), the most common causes of sleep loss are those pertaining to work-related factors and contemporary lifestyle. In the past 40 years, particularly in Western societies, various technological (e.g., mobile phones) and societal (e.g., 24 hour lifestyle) changes have significantly increased the number of workers facing sleep loss (Luckhaupt, Tak & Calvert, 2010). Shift work and long work hours particularly put individuals at risk of short sleep duration and sleep disturbance (Caruso, 2014).

Any industry which operates 24 hour activities is highly susceptible to human error as a result of sleep loss and fatigue (Moore-Ede, 2003). The nursing, medical, mining, maritime, and transport industries are all susceptible to sleep loss and tragically, it has been implicated, in addition to various additional contributory factors, in several catastrophic incidents and accidents such as the Chernobyl (1986) and Three Mile Island (1979) nuclear power plant explosions and the Challenger space shuttle crash (1986) (Reason, 1990). Commercial aviation is an additional industry which is suspectible to sleep loss and associated fatigue among its workers as a result of round-the-clock operations however, it has received relatively limited attention in regards to the scientific evaluation of the impact of sleep loss and associated fatigue on wokers performance. The stakes in aviation differ from that of other transport operations due to the involvement of multimillion-dollar airframes and the lives of up to 555 passengers (Caldwell, 2012). A single major civil aviation accident can have major financial losses (in exceedance of $500 million (~€384) in total), inestimable personal suffering and a calamitous mishap on airline revenues (Caldwell, 2005).

The current Flight Time Limitations (FTL's) at the time of this research, which are set out by the European Aviation Safety Agency (EASA), first came into effect in July 2008. These legally binding minimum set of FTL safety rules are purported to prevent pilot fatigue across Europe but are not based on sound scientific evidence regarding their ability to adequately prevent pilot fatigue (Moebus, 2008). Furthermore, the newest version of the regulations, which came in to effect in February 2016, are proposed to still contain many of the shortcomings identified in the 2008 regulations. The Danish, Norwegian and Swedish Airline Pilots Association conducted surveys between 2010 and 2011 investigating pilot experiences working under the 2008 FTL regulations. Results found very high incidences of fatigue in the cockpit and insufficient rest and sleep among pilots. Findings suggest that loss of sleep and fatigue may be a very serious and widespread problem among European pilots. In 2012, the European Cockpit Association (ECA) produced a 'Pilot Fatigue Barometer' which investigated the prevalence of fatigue in Europe's cockpits. Results concluded fatigue among European pilots to be a very common and under-reported safety issue with over 50% of those surveyed reporting experiencing fatigue levels which they found to impair their abilities while on duty (ECA, 2012).

Commercial airline pilots now work on a pressurised 24/7 timetable, typically operating long working shift-work hours, and are subjected to demanding, complex and stressful working environments. The unrelenting, ever-expanding, escalation in international long-haul, short-haul, regional and overnight operations will continue to increase these round-the-clock requirements (Åkerstedt et al., 2003). Loss of sleep and associated fatigue are proposed to be a major risk to flight safety and key causes of pilot error (Caldwell et al., 2009; Petrilli et al., 2006b). Additionally, the U.S. National Transportation Safety Board (NTSB) have identified fatigue as a major culprit in fatal accidents in commercial aviation operations with pilot fatigue being on the U.S. NTSB's 'Most Wanted List' of safety-related priorities since 1990 (Caldwell, 2005). From a flying performance perspective, as fatigue increases, accuracy and timing decline, attention narrows, decrements in performance are accepted and pilots' abilities to integrate information from individual flight instruments into a significant overall pattern become impaired (Caldwell & Caldwell, 2003). Lapses in attention or disregard for vital aspects of flight tasks ensue and reductions in ability to efficiently time-share mental resources occur (Caldwell, 2005). Loss of sleep and fatigue are proposed to have very serious consequences on pilot performance. However, a vast amount of the sleep loss literature has tended to focus on cognitive processes which have little relevance to the true nature of a particular occupation or normal working duties (e.g. serial reaction time). This can result in conflicting findings and a simultaneous reduction in performance tasks which are of no known relevance to the occupation-specific skills.

The advancements in aviation technology and operational demands as well as the increase in today's commercial flight operations resulting in a 24/7 industry means commercial airline pilots are presently highly susceptible to sleep loss and fatigue. Research in the commercial aviation-specific domain is, to date, somewhat limited with no previous studies investigating the effects of sleep loss and fatigue on flying performance of commercial airline pilots. Several European pilot surveys are proposing high levels of sleep loss and fatigue among commercial airline pilots (DALPA, 2011; NRK, 2010; SWALPA, 2011). However, no such research has ever been conducted in an Irish context despite been proposed to have in excess of 3,000 commercial airline pilots and being home to Europe's largest low cost airline. Sleep loss and fatigue result in impairments in both working performance and health and well-being (Russo et al., 2005) and could pose a serious threat to flight safety. This is of grave concern considering Dublin airport alone handled 27.9 million passengers in 2016, averaging 541 flights every day (Dublin Airport, 2017). This equates to a pilot taking off or landing in Dublin airport every 2 minutes. With +100 passengers per flight, any mistake or error could prove catastrophic. Research investigating the prevalence and impact of sleep loss and fatigue among commercial airline pilots is therefore required. Enhancing our understanding of these factors in a commercial aviation environment would aid in improving flight safety and promote pilot mental health and well-being (Åkerstedt et al., 2011).

1.2 Aim and Objectives of the Study

Aim of Research:

The aim of this research was to examine the influence of sleep loss and associated fatigue on incidents in flight and mental health, and to investigate its effects on performance in commercial airline pilots.

Primary Objectives:

1. To evaluate a general work hours/incident model to identify the interplay of factors contributing to incidents in flight (*Chapter 3 – Study 1*).

2. To explore differences in self-reported depression or anxiety among commercial airline pilots (*Chapter 4 – Study 2*).

3. To investigate the effects of 24 hours' sleep deprivation on commercial airline pilots' mood, pilot-specific competencies and flying performance (*Chapter 6 – Study 4*).

Secondary Objectives:

1. To investigate the attitudes and experiences of commercial airline pilots to sleep disturbance and fatigue working under the current Flight Time Limitation regulations (*Chapter 3 – Study 1).*

2. To investigate the effects of 24 hours' sleep deprivation on mood, fatigue and pilot-specific competencies among a group of university level students (*Chapter 5 – Study 3*).

3. To explore if changes in specific psychological measures and cognitive tests are related to changes in flight performance over a period of 24 hours' sleep deprivation (*Chapter 6 – Study 4*).

1.3 Thesis Structure

Following the Introduction, Chapter 2 critically reviewed and evaluated the scientific literature on sleep and the sleep-wake cycle; sleep loss and its projected causes and consequences; the current Flight Time Limitation regulations; and core pilot competencies required in commercial aviation. Chapters 3 to 6 addressed the primary and secondary objectives of this thesis in a series of separate but inter-related studies which seek to address these objectives. Chapter 3 looked at the proposal of a general work hours/incident model whilst Chapter 4 is a cross-sectional study that explored differences in self-reported depression or anxiety among commercial airline pilots. Chapter 5 presents a pilot study which explored the effects of sleep deprivation on mood, fatigue and airline pilot competencies among a group of university level students whilst Chapter 6 investigated the effects of sleep deprivation on mood, fatigue, airline pilot competencies and flying performance on a group of commercial airline pilots. All studies from Chapter 3 to Chapter 5 (Study 1, 2 & 3) are published in peer-reviewed journals. Study 4 in Chapter 6 is presently under review. Chapter 7 provides an overall discussion whilst Chapter 8 discusses the strengths and limitations of the thesis, directions for future research, an overall conclusion and impact of the research.

Chapter 2: Review of the Literature – The literature review examined and critically evaluated the existing research in the areas of sleep and the sleep-wake cycle; sleep loss its projected causes and consequences; the current Flight Time Limitation regulations; and core pilot competencies required in commercial aviation. The purpose of this was to synthesise various ideas, results, and evidence which informed the structure and focus of this thesis.

Chapter 3: Study 1: Duty Hours and Incidents in Flight Among Commercial Airline Pilots – This study investigated a work hours/incident model to identify the interplay of factors contributing to incidents in flight within the aviation industry.

Chapter 4: Study 2: Flying Into Depression – Pilot's Sleep and Fatigue Experiences Can Explain Differences in Perceived Depression and Anxiety Associated With Duty Hours – This study investigated the differences in self-reported depression or anxiety among commercial airline pilots, and then further investigated the extent to which these differences could be explained, initially by individual demographic characteristics (e.g., age, position, employment), and subsequently by experiences of fatigue in the cockpit, experiences of microsleeps in the cockpit, and sleep disturbance due to work schedule.

Chapter 5: Study 3: A Pilot Study Exploring the Effects of Sleep Deprivation on Analogue Measures of Pilot Competencies – This pilot study explored the effects of 24 hours' sleep deprivation on mood, fatigue and analogue measures of airline pilot competencies in a group of university level students employing a repeated-measures study design.

Chapter 6: Study 4: "Flying on Empty" – Effects of Sleep Deprivation on Pilot Performance – This study investigated the effects of 24 hours' sleep deprivation on mood, airline pilot competencies and flying performance of commercial airline pilots. It also explored changes in specific psychological measures and cognitive tests to determine if they are related to changes in flight performance during the period of continuous wakefulness.

Chapter 7: Overall Discussion – This chapter combined and discussed the key findings across each of the studies in light of the existing scientific literature to provide a universal discussion to this thesis.

Chapter 8: Conclusions and Future Recommendations – The strengths and limitations of this thesis were discussed followed by suggestions for future research. An in-depth summary and a discussion on the impact of the research concluded this chapter.

Chapter 2

Review of Literature

2.1 Introduction

On December 17th 1903, Orville Wright flew the first successful, piloted flight in history invented by him and his brother, Wilbur Wright. In the past 115 years, such advancements and developments have occurred within the aviation domain that transcontinental and transoceanic routes, night-time departures and early-morning arrivals are now all possible (Caldwell, 2012). In today's flight operations, commercial airline pilots are required to consistently perform in highly demanding, complex and stressful environments on a 24/7 timetable (Caldwell et al., 2009). Characteristics of the aircraft and various other operational aspects such as noise, vibrations and the cockpit environment all influence pilot performance while numerous human parameters such as age, nutrition, socioeconomic factors, drug use and sleep will also have an impact (Lindgren, Andersson & Norbäck, 2006). Sleep is a particularly important component to consider. Loss of sleep and associated fatigue are proposed as major causes of pilot error (Caldwell et al., 2009). Any industry which operates 24 hour activities is highly susceptible to human error as a result of sleep loss (Moore-Ede, 2003). This is of serious concern in the commercial aviation domain, particularly within a Eurpoean context, and one which requires further investigation. Enhancing our understanding of sleep loss in a commercial aviation environment would aid in accident prevention and promote safety (Åkerstedt et al., 2011).

The following literature review briefly discussed the concept of sleep with particular reference to the sleep-wake cycle and the proposed functions of sleep. Following this, sleep loss and its projected causes are deliberated. The consequences of sleep loss are then discussed ensued by sleep factors in the aviation industry. Core competencies of commercial airline pilots and the proposed impact of sleep loss on these variables as well as methods of measurement are then be debated. A brief summary concludes this review.

2.2 Sleep

Humans sleep on a daily basis and this activity occupies approximately one-third of life (Aminoff, Boller, & Swaab, 2011). Across an 85-year life span, an individual may sleep up to 250,000 hours, or over 10,000 full days. Throughout the years, many poets, novelists and philosophers have recognised the influence of sleep. In his Iliad, Homer acknowledged the power of sleep in its ability to make both men and Gods bow in submission (Homer, 1025).

Scientists have also been perplexed by sleep. In an attempt to decipher the unknowns of this "gentle tyrant" (Webb & Agnew Jr, 1975), numerous researchers have explored and examined the purpose of sleep, stages of sleep, underlying mechanisms involved in sleep regulation as well as the effects and impact of sleep loss (Waters & Bucks, 2011).

A broadly held, although basic, operational definition of sleep is that of a natural state characterised by a decline in voluntary motor activity, a reduced response to stimulation (i.e., greater arousal threshold), and stereotypic posture (Fuller, Gooley & Saper, 2006). Sleep is a reversible state of cognitive and sensory disengagement from the environment but is also a complex combination of physiologic and behavioural processes necessary for survival (Carskadon & Dement, 2011; Hardin, 2009). It is considered a vital and multifaceted component of life, which is essential for physical, cognitive and emotional well-being (Banks & Dinges, 2007). Sleep is an essential biological phase within the daily life-cycle without which life would not continue (Krueger et al., 2016). Humans are ultimately programmed to be active during the day and to sleep during the night. The interactions of two biological systems (i.e., the (i) circadian rhythm and the (ii) homeostatic drive) largely determine this transition from wakefulness to sleep and vice versa. This is referred to as the sleep-wake cycle.

2.2.1 Sleep-Wake Cycle

The sleep-wake cycle (or the two-process model of sleep regulation) was initially proposed more than three decades ago by the Swiss sleep researcher Alexander Borbély and is still considered a prevalent conceptual model today (Borbérly et al., 2016). According to the model, sleep is regulated by two separate biological systems: (i) circadian rhythm (Process C) and (ii) homeostatic drive (Process S) (Borbély, 1982).

i) **Circadian Rhythm:** The first biological system refers to the circadian rhythm which is also referred to as Process C. A circadian rhythm is any biological process which contains an endogenous, entrainable oscillation of approximately 24 hours. For example, sleeping at night and being awake during the day (i.e., the sleep/activity cycle) is considered a light-related circadian rhythm. Furthermore, in a majority of mammals, including humans, body temperature, blood pressure, circulating hormones, and metabolism, as well as various other physiological parameters all contain 24 hour rhythms (Buhr & Takahashi, 2013). All animals and plants possess endogenous circadian rhythms which are entrained to the environment by external cues which are referred to as zeitgebers (a German word meaning 'time-givers'). There are various zeitgebers such as temperature, melatonin and meal times but daylight is considered the most important of all zeitgebers (Youngstedt et al., 2016). However, even in the absence of external cues, circadian rhythms still continue due to their endogenous nature.

Circadian rhythms are governed by the suprachiasmatic nucleus (SCN) which is located in the hypothalamus region of the basal forebrain. It is considered the brain's 'master clock'. One of the primary roles of the master clock is to promote wakefulness during the day and to facilitate the consolidation of sleep during the night (Kryger, Roth & Dement, 2010). The SCN is entrained to the 24 hour day on a daily basis by light input from the retina during the day and by melatonin secretion from the pineal gland during the dark cycle (i.e., night time) (Duffy & Czeisler, 2009). During the day, light signals from the retina are transmitted by the retinohypothalamic tract to the SCN. As light enters the eye, it activates neurons in the retina which convert photons (light particles) to electrical signals. These electrical signals are transmitted via the retinal neurons from the retina to the SCN (Paul, Saafir, & Tosini, 2009). The SCN then relays phase information to the rest of the brain and body via a combination of neural, humoral and systemic signals (Buhr & Takahashi, 2013). During the night, and in the absence of light, the SCN relays this phase information (i.e., night-time) to the pineal gland which in turn stimulates the release of melatonin, also known as the hormone of darkness, from the pineal gland (Hardeland, 2013). Melatonin production throughout the body induces physiological changes which promote sleep such as a reduction in body temperature and respiration rate. Melatonin displays robust 24 hour rhythms (Hofstra & Weerd 2008). The duration of melatonin secretion parallels the duration of the dark period as a result of suppressing effects of light on melatonin (Burgess & Fogg, 2008). Melatonin secretion begins in the early evening when light fades and tends to peak between 02:00 and 04:00 before it begins to dissipate reaching near zero levels again in the early/mid-morning after waking (Burgess & Lockwood, 2006). As melatonin secretion is dependent on the duration of darkness, greater amounts of melatonin is secreted over a 24 hour period in winter than in summer (Burgess & Lockwood, 2006).

These timing signals keep the clock in synchrony with the external day-night cycle. Whilst both wakefulness and sleep are modulated by the master clock located in the SCN, the master clock also modulates hour-to-hour waking behaviour as indicated in fatigue, alertness and performance levels. The master clock generates circadian rhythmicity in nearly all neurobehavioural variables (van Dongen & Dinges, 2005). Scientific studies have found that, based on circadian factors, there appears to be two periods of maximal sleepiness throughout a 24 hour day. One occurs approximately between 03:00 and 05:00, with various physiological and performance parameters indicating reduced levels from 00:00 to 06:00, whilst the other occurs during the day approximately between 15:00 and 17:00. Interference with one's circadian rhythm to accommodate amendments in unconventional working hours have been found to be associated with considerable impairments in performance. Circadian rhythms are not sufficient to cause and regulate sleep on their own and as such require the homeostatic sleep drive also.

ii) **Homeostatic Sleep Drive:** The second biological system refers to the homeostatic sleep drive which is also referred to as Process S. While the exact nature of 'sleep drive' remains unknown, it has been hypothesised as a homeostatic pressure which builds during the waking period and dissipates during (non-REM) sleep (Stickgold & Walker, 2010). It is proposed that sleep-wake homeostasis is an internal biochemical system which functions as a 'timer' which generates a homeostatic sleep drive or pressure to sleep and regulates the intensity of sleep. The homeostatic drive is dependent on sleep and wakefulness and represents sleep debt. Therefore, as wakefulness continues, the need for sleep increases. Furthermore, it acts as a reminder informing the body it needs to sleep after a certain time. It is a highly intuitive system; the longer the period of wakefulness, the greater the desire to sleep becomes with the likelihood of falling asleep increasing; conversely the longer one has been asleep, the pressure to sleep dissipates and the likelihood of awakening increases (Gillete & Abbott, 2005). This process is involved in the accumulation of hypnogenic (sleep-inducing) substances in the brain which generate a homeostatic sleep drive. The cellular substrate utilised in this homeostatic sleep drive is unknown, however it is thought that an endogenous somnogen, specifically adenosine, plays a critical role (Dittrich et al., 2015). Adenosine (a chemical by-product of cellular energy consumption) is a naturally occurring purine nucleoside that is proposed to accumulate during waking, and on reaching sufficient concentrations, impedes neural activity in wake-promoting circuitry of the basal forebrain likely activating sleep-promoting ventrolateral preoptic nucleus (VLPO) neurons which are located adjacent to the basal forebrain (Saper et al., 2005). The homeostatic drive increases during wakefulness and declines during sleep. Its values oscillate within a range that is periodically entrained to day and night by the body's internal clock. When the homeostatic drive nears the range’s lower boundary, it triggers awakening, whilst it triggers sleep near the upper boundary.

The timing of sleep and waking is regulated by the interaction of these two processes (Achermann, 2004). While the individual working of each process is relatively well known, the exact mechanisms of their combined interactions remain somewhat unclear (Garbazza et al., 2016). The homeostatic sleep drive increases throughout the day, thus making a person more and more sleepy, and is countered and moderated by the circadian rhythm for arousal, at least until late evening, when the circadian rhythm for arousal dissipates and initiates sleep-inducing melatonin production. This results in the opening of the ‘sleep gates’, identified as the point where the homeostatic sleep drive is at its furthest distance above the circadian drive for arousal (see Figure 2.1). During the night, when one is sleeping, the homeostatic sleep drive begins to dissipate while the circadian-regulated melatonin production continues. In the early morning, melatonin secretion ceases and the circadian alerting system increases its activity again. Eventually a point is reached in which the circadian drive for arousal begins to overcome the homeostatic sleep drive (identified in Figure 2.1 where the two curves meet) activating awakening and the processes begin all over again.

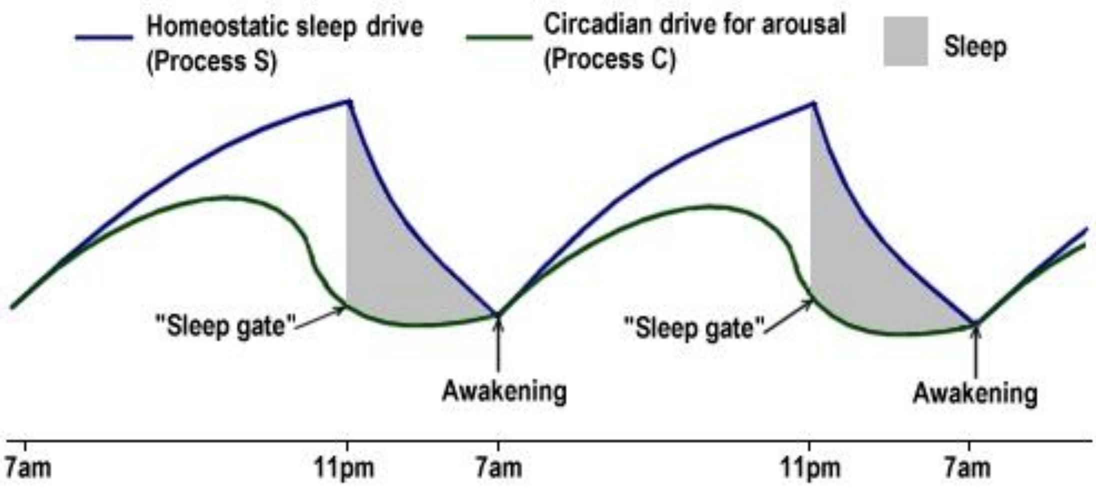

Figure 2.1. Sleep-wake regulation: interaction between the homeostatic sleep drive (Process S) and the circadian drive for arousal (Process C) (image by Luke Mastin).

2.2.2 Functions of Sleep

Despite it constituting a large portion of human life, the fundamental purpose or function of sleep is not fully known or understood (Walker, 2008). According to Allan Rechtschaffen, “if sleep does not serve an absolutely vital function, then it is the biggest mistake the evolutionary process has ever made” (1971, p. 88). It is considered the last major physiological process for which this is a lack of consensus regarding its function. Whilst asleep, one is unable to eat, drink, reproduce and is susceptible to predation due to a state of reduced responsiveness to environmental stimuli (Krueger et al., 2016). It is assumed sleep must provide some evolutionary advantage which is greater than these apparent negative factors of sleep.

Numerous proposals have been made regarding the function of sleep (Krueger et al., 2016). According to one theory, sleep serves as an immune function. Historically, those in the medical profession proposed sleep as an aid for recuperation from disease states. It was formally proposed that sleep acts as host defences following the discovery that bacterial products and endogenous response modifiers enhance sleep (Krueger, Walter & Levin 1985). An additional theory proposed that the purpose of sleep is to reduce caloric use. Resting waking basal metabolic rate is lower than whole-organism metabolic rate (Walker et al., 1981). This premise is linked with the idea that energy stores depleted during wakefulness are restored during sleep. Additionally, Belenky et al., (2003) suggest sleep restores waking-induced performance degradation. Loss of sleep impairs cognitive and behavioural performance which can be seen at the whole-organism cognitive-behavioural level (van Dongen et al., 2003). The level of impairment is wake-dependent and use-dependent (van Dongen, Belenky & Krueger, 2011). Performance is restored by sleep following a period of sleep loss in a sleep dose-dependent manner (Banks et al., 2010) (i.e. the more sleep obtained, the greater the gain). Therefore, sleep is proposed to restore optimal performance. Whilst several hypotheses and theories have been proposed as justifications for the function of sleep, a unified theory of sleep function remains elusive (Fuller, Gooley & Saper, 2006).

Whilst the function or purpose of sleep remains a major scientific enigma, there is vast scientific evidence concluding that sleep is a vital physiological need state which must be satisfied to ensure survival (Krueger & Obal Jr, 2003). Efforts to identify and clearly establish the biological function of sleep have been surprisingly difficult. Despite an incomplete understanding of the mechanisms and events surrounding sleep in humans, certain indisputable facts remain such as links between sleep loss and reductions in physical (e.g. power output), cognitive (e.g. attention and vigilance) and emotional (e.g. stress) functioning and well-being (Banks & Dinges, 2007; Van Dongen et al., 2004).

2.3 Sleep Loss

Sleep loss refers to a complete lack of sleep across a certain period of time or a shorter than optimal sleep period (Orzel-Gryglewska, 2010). Sleep loss may occur as a result of total sleep deprivation (i.e., no sleep for a period of time (at least one night) resulting in prolonged wakefulness), chronic sleep restriction (i.e., shorter sleeping period which is less than an individuals typical baseline sleep or sleep required on a regular basis for optimal performance) or sleep fragmentation or disruption (i.e., the interruption or fragmentation of sleep in which regular arousals intefere with the normal dynamics of sleep) (Reynolds & Banks, 2010).

Loss of sleep is a common occurrence in modern civilisation (Bonnet et al., 2005; Zager et al., 2007). Humans are the only animals who opt to achieve less sleep than is required by their biological clocks and their sleep needs (Turek, 2005). In today's society and culture, sleep loss is considered a norm as opposed to an exception with value placed on the attempt to reduce sleep time. The notion prevails that loss of sleep is not important and can be overcome by force of will (Turek, 2005). However, these inferences are unsafe and perilous with loss of sleep found to significantly impair behavioural, physiological and neurocognitive functioning and as a result, negatively impact performance (Scott, McNaughton & Polman, 2006; Waters & Bucks, 2011). Sleep loss can have very serious consequences which can result in catastrophic outcomes. For example, loss of sleep, in addition to various additional contributory factors, has been found to impact well-known serious industrial events such as the Chernobyl (1986) and Three Mile Island (1979) nuclear power plant explosions, the Challenger space shuttle crash (1986) and the running aground of the Exxon Valdez (1989) and the Shen Neng in the Great Barrier Reef (2010) (Reason, 1990). It is vital that sleep loss is further explored and understood to promote and enhance safety and well-being.

2.3.1 Causes of Sleep Loss

Loss of sleep may occur as a result of various factors such as sleep or circadian disorders (e.g., insomnia, restless leg syndrome) (Zhu & Zee, 2012), work-related factors (e.g., shift work, long working hours) (Basner et al., 2007), pharmacologic factors (e.g., caffeine, stimulants) (Drake et al., 2013), emotional or psychological factors (e.g., stress, depression) (Åkerstedt, Kecklund & Axelsson, 2007), environmental factors (e.g., noise, light) (Yang et al., 2010), lifestyle factors (e.g., social activities) (Orzel-Gryglewska, 2010) or health factors (e.g., illness, pain) (Finan, Goodin, & Smith, 2013). According to Orzel-Gryglewska (2010), the most common causes of sleep loss are those pertaining to work-related factors and contemporary lifestyle. In the past 40 years, particularly in Western societies, various technological (e.g., mobile phones) and societal (e.g., 24 hour lifestyle) changes have significantly increased the number of workers facing sleep loss (Luckhaupt, Tak & Calvert, 2010). Shift work and long work hours particularly put individuals at risk of short sleep duration and sleep disturbance (Caruso, 2014). These factors can result in demanding working schedules which can cause sleep difficulties due to the need to sleep at irregular times and at times that are out of phase with circadian rhythms (Caruso, 2014). When sleep and circadian rhythms are misaligned, this can result in difficulties falling asleep, early awakenings and greater arousal during sleep which can cause poorer sleep quality and short sleep duration.

2.3.1.1 Shift Work

Shift work is associated with sleep loss, circadian rhythm disruption and increased fatigue (Åkerstedt, 2003; Lac & Chamoux, 2003). Typically, shift work refers to work schedules in which the 24 hours are divided into roughly similar sizes and three or more teams are utilised to provide 24 hour coverage. Teams can remain permanent or alternate between (i) early morning, (ii) afternoon or (iii) night shifts. Rotating shifts tend to be more popular in Europe. ‘Roster work’ is a term employed to indicate schedules which are more irregular in nature but still cover all, or a majority, of the 24 hours. Roster work is more common in transport work such as aviation. However, both shift work and roster work experience the same conflicts between circadian regulation and the sleep/work pattern (Åkerstedt, 2003). Shift workers almost always report greater levels of sleep disturbance and excessive sleepiness in comparison to day workers. In 2016, Safefood Ireland conducted the nationwide Healthy Ireland Survey involving 7,498 participants. Results indicated that two thirds (66%) of shift workers were not getting the recommended seven to nine hours sleep per 24 hours (Healthy Ireland Survey, 2016). Truck drivers, miners, nurses, doctors, pilots and military personnel who operate a shift/roster work schedule are all vulnerable to the consequences of sleep loss (Hege et al., 2015). A major issue is that shift workers behavioural sleep-wake schedules are out of sync and in direct opposition to their endogenous rhythms (Åkerstedt, 2003). From a circadian standpoint, sleep is optimal during the biological night whilst cognition is optimal during the biological day (Åkerstedt, 2003). With shift work, there is conflict between the day-oriented circadian physiology and working and sleeping requirements at the 'wrong' biological time of the day (Åkerstedt, 2003). Working hours which require workers to sleep during the day and to work during the night interfere with the circadian and homeostatic regulation of sleep. Shift work schedules often require workers to work during the biological night when the circadian system promotes sleep, and sleep to occur during the biological day whe the circadian system promotes wakefulness. This results in a misalignment between internal circadian time and the required sleep-wake work-rest schedules resulting in impaired wakefulness and disturbed sleep (Åkerstedt, 2003).

2.3.1.2 Long Working Hours

Several studies have found that long weekly working hours and overtime are associated with shorter sleep duration or sleep disturbance. According to Aguirre et al., (2004) sleep duration is shorter with a 12-hour day shift (06:00 – 18:00) than an 8-hour day shift (07:00 – 15:00). Furthermore, in a study among nurses, it was found that those who worked 12-hour shifts reported a mean sleep duration of 5.5 hours (Geiger-Brown et al., 2012). According to Basner et al., (2007) one additional hour of work per day is typically associated with one half-hour less sleep. In a review conducted by Knauth (2007) on extended work shifts, it was found that 13 studies indicated that shifts greater than 8 hours had a negative influence on sleep, 8 studies indicated mixed results while 4 studies showed a positive effect. However, according to Knauth (2007), there are numerous methodological issues and contradictory results recorded in many of the cited studies meaning no firm conclusions can be drawn from the reviewed studies. Long duty hours have the potential to increase acute sleep loss and extend periods of wakefulness (Gander et al., 2013). Poor recovery following work was identified as a plausible causal pathway between long working hours and sleep disturbance (Virtanen et al., 2009). Virtanen and colleagues (2009) propose that a certain amount of recovery time may be required following a working day as a natural consequence of fatigue, as a result of the efforts expended at work. This recovery may not only include sleep but also relaxation, such as resting, reading or spending time with family and friends. According to Jansen et al., (2003) longer working hours have been found to be associated with a greater need for recovery after work. This suggests that these workers would actually require more time to recover than those working shorter work schedules.

2.3.1.3 Stress

Stress is an additional factor which can have a substantial negative impact on sleep (Åkerstedt, Kecklund & Axelsson, 2007). Those under constant stress or who have abnormally exaggerated responses to stress often tend to have sleep issues (Nofzinger, 2005). In Janurary 2013, the Sleep Council conducted a survey on 5,007 UK adults. They found that almost half (47%) of those surveyed reported losing sleep as a result of worry or stress. Higher daily stress was found to be associated with lower sleep efficiency and increased time awake (Åkerstedt, Kecklund & Axelsson, 2007). Shift work is one factor that has been found to be associated with feelings of stress (Costa, 2010). Psychological stress is associated with emotional arousal which in turn causes physiological arousal (e.g. increased heart rate, cortisol, adrenaline). Stress influences sleep by making the body aroused, awake and alert (Nofzinger, 2005). When feeling stressed, the amygdala, located in the brain, transmits a distress signal to the hypothalamus which in turn activates the sympathetic nervous system by sending signals via the autonomic nervous system to the adrenal glands. The glands respond by pumping the hormone epinephrine (i.e., adrenaline) into the bloodstream. This results in various physiological changes such as increased heart rate, blood pressure, pulse rate, breathing rate, oxygen uptake and alertness. Furthermore, it triggers the release of blood sugar (i.e., glucose) and fats from temporary storage sites in the body in to the bloodstream also supplying energy to all parts of the body. This increase in arousal, alertness and energy can result in difficulties in sleep initiation or on returning to sleep after awakening during the night (Basta et al., 2007). However, it can also act in a somewhat cyclical manner in that loss of sleep can reduce one's psychological threshold for the perception of stress from cognitive demands (Minkle et al., 2012). Therefore, insufficient sleep can increase the likelihood of perceiving more factors as stressful which in turn adds to one's stress levels which in turn can have consequential effects on sleep.

2.3.2 Theoretical Perspectives of Sleep Deprivation

Various explanations have been proposed to explain the influence of sleep loss on cognition. Theories range from predicting an overall reduction in cognitive functioning to suggestions of precise declines in executive functions (Ratcliff & Van Dongen, 2009). Three general viewpoints on the theoretical framework surrounding sleep deprivation exist – (i) the 'Controlled Attention Hypothesis'; (ii) the 'Neuropsychological Hypothesis' and; (iii) the 'Vigilance Hypothesis'. It should be noted that these theories are not considered to be mutually exclusive and are open to integration (Lim & Dinges, 2010). However, regardless of the increasing literature content on the topic, the fundamental mechanisms and chain of events that underlie sleep deprivation remain to be understood (Leibowitz et al., 2006).

i) The 'Controlled Attention Hypothesis': Early studies of sleep deprivation and cognition regularly cited novelty and motivation as key variables in determining performance under adverse conditions (Wilkinson, 1961; Williams, Lubin, & Goodnow, 1959). These suggestions were made following initial inconsistent findings that numerous demanding cognitive tests were not impacted by short bouts of total sleep deprivation (e.g., Baddeley's Logical Reasoning Test) (Magill et al., 2003). These negative findings resulted in the development of theories such as the 'Controlled Attention Model' by Pilcher, Band, Odle-Dusseau, and Muth (2007). The authors of this model highlight the importance of 'bottom-up' task characteristics, suggesting that tasks which are monotonous or intrinsically less appealing are more severely influenced by sleep deprivation. As a result greater 'top-down' control is required in order to maintain optimal performance on these tasks. This hypothesis basically states that task characteristics depending on how engaging they are dictate the degree to which they are influenced by sleep deprivation. Therefore, tasks which are simpler, more monotonous and less engaging are more affected as these tasks require 'top-down' control for optimal performance which is depleted during sleep deprivation. According to Pilcher and colleagues, tasks should be classified based on whether they encourage attentive behaviour and suggest that tasks which are high on this dimension are least influenced by sleep deprivation (Lim & Dinges, 2010). Additionally, the 'lapse hypothesis' (Dinges & Kribbs, 1991) was proposed in an attempt to understand the effects of sleep deprivation. According to this theory, baseline levels of functioning are identical in both sleep-deprived and rested states. However, sleep-deprived individuals experience temporary phases of low arousal during which sleep intrusions and lapses in performance occur. Whilst this theory has some explanatory power, findings from chronic sleep restrictions studies (Dinges et al., 1997) suggest that it does not account for the changes in neurobehavioural functioning which occur over time. For example, the increased variability of reaction times on the Psychomotor Vigilance Task (PVT) as hours of wakefulness increases would not be predicted by the 'lapse hypothesis' alone. According to Doran and colleagues (2001), reductions in performance during sleep deprivation are due to moment-to-moment variability of attention caused due to the interaction of the homeostatic drive for sleep, the circadian drive for wakefulness, and compensatory effort to perform. It was hypothesised that the variability in performance, as a result of an inability to sustain attention, would transgress across a wide range of cognitive tasks since attention is a key requirement of numerous goal-directed activities (Doran et al., 2001).

ii) The 'Neuropsychological Hypothesis': Several proposals have been made that sleep deprivation has domain-specific effects on cognitive function, particularly those mediated by the prefrontal cortex (PFC) – i.e., the 'prefrontal lobe hypothesis'. The PFC is considered the linchpin for carrying out executive functions (i.e., complex cognitive processes) such as planning and sequencing thoughts and behaviours, updating information, inhibiting inappropriate thoughts or actions and thinking flexibly, divergently and innovatively (Curtis & D'Esposito, 2003). According to Jones and Harrison (2001) and Harrison and Horne (2000), who both conducted reviews on the influence of sleep deprivation on PFC-orientated tasks, tasks which target the PFC provide clear validity in evaluating impairments beyond the consideration of vigilance or sustained attention alone. Sleep loss is proposed to exclusively influence the proficiency of the functioning of the PFC resulting in provisional changes in the cerebral metabolism which, in turn, results in alterations in cognitions, emotions and behaviour which coincides with mild prefrontal lobe dysfunction (Killgore et al., 2008). This hypothesis proposes that sleep deprivation results in a temporary 'functional lesion' which targets the frontal and prefrontal areas. Following 36 hours total sleep deprivation, Harrison, Horne and Rothwell (2000), provided young adults with a neuropsychological battery. The authors found specific declines on PFC-oriented tasks (i.e., on temporal memory, verbal fluency, and response inhibition) but not on recognition memory. According to the study findings, the observed declines were similar to those displayed by healthy, middle-aged (55 – 64 years) participants with impairments of PFC function which occur as a consequence of normal aging. Furthermore, neuroimaging data further support these claims. Using functional magnetic resonance imaging (FMRI), several studies (e.g., Chee & Choo, 2004) have shown hypoactivation in the lateral and medial regions of the PFC in a variety of tasks following sleep deprivation thus highlighting the proposed neural basis for the observed behavioural changes. Supporters of this view construe these findings as a clear indication that impairments observed in complex tasks do not merely occur as a result of the failure of more basic cognitive skills, but that in fact PFC-oriented tasks are vulnerable to specific failures which are above and beyond those expected to occur as a result of low arousal and sleepiness. Theoretically, this can be considered a neuropsychological model in that sleep deprivation results in a reversible functional lesion in the PFC which can be detected via tests sensitive to these deficits in those with brain injuries. This model contains some form of explanatory power in determining the mixed findings in the literature which researchers have attempted to account for with moderators such as task type, task length, novelty, and motivation (Lim & Dinges, 2010). However, this model has received mixed support with numerous studies reporting impairments on executive function tasks during sleep deprivation (i.e., Nilsson et al., 2005), whilst others did not find any such effects (i.e., Tucker et al., 2010). According to Kilgore (2010), the challenge now facing researchers is to determine which executive function tasks are impacted by sleep loss and to derive a unifying explanation as to why some executive functions are impaired whilst others remain unaffected as a result of insufficient sleep.

iii) The 'Vigilance Hypothesis': Arousal and vigilance have been identified as general factors which may explain the variance in cognitive declines following a period of sleep loss by several researchers. According to the 'vigilance hypothesis' (Doran et al., 2001; Williams, 1959), the interaction between the need for sleep and circadian factors cause fluctuating arousal levels which in turn interfere with both neural and cognitive performance. Variations in attention result in mental lapses during which variable patterns of cognitive performance are observed. This hypothesis states that sustained attention is considerably impacted by sleep deprivation and that sustained attention is fundamentally important for higher aspects of cognition (Lim & Dinges, 2010). An additional hypothesis proposed is the 'wake-state instability' hypothesis (Doran et al., 2001). According to this hypothesis, sleep deprivation does not result in reductions in executive function tasks due to selective declines in the prefrontal cortex, but at least in part due to reductions in one's ability to maintain attention. This hypothesis suggests that waking-state function declines following sleep deprivation as a result of both lapses in attention and a reduction in tonic aspects of functioning (Doran, van Dongen, & Dinges, 2001). As loss of sleep continues, performance variability increases in a way which is reflective of the interaction of the homeostatic drive for sleep and the internal circadian drive for wakefulness, and the compensatory effort displayed by participants to maintain performance. Following a substantial period of sleep loss, normal responses are not sustainable over time, despite compensatory effort, due to sleep initiation processes chronic intrusion into wakefulness. These global declines in cognitive functioning are responsible for the increased variability in performance as well as a reduction in the fastest or optimal responses. According to Durmer and Dinges (2005), cognitive tasks substantially differ in their sensitivity to sleep loss. However, they did comment that reaction time measures of attention and vigilance based tasks are predominantly utilised to determine vulnerability to sleep deprivation. Furthermore, Lim and Dinges (2008) also highlighted vigilant attention as a cognitive process that is consistently and vigorously impacted by total sleep deprivation. Balkin and colleagues (2008) stated that such a wide variety of activities are impacted by sleep loss that it could be assumed that loss of sleep exerts a non-specific effect on cognitive performance. Substantial evidence exists for these assertions. Tests of sustained attention, such as the Psychomotor Vigilance Task (PVT), are considered highly reliable but also valid measures in predicting real-world performance and in determining level of impairment under conditions of fatigue (Lim & Dinges, 2010). The PVT is also sensitive to both circadian and homeostatic variances in attention and arousal and tends to be the dominant measure used to assess vigilant attention in sleep deprivation experiments (Minkle, 2010). Models of attention often highlight that sustained attention and vigilance are fundamentally imperative to numerous higher components of cognition and that these higher processes essentially decline if a participant is unable to maintain an appropriate level of vigilance whilst performing a task (Langner & Eickhoff, 2013). However, in a study by Lo et al., (2012), they found that whilst sustained attention was sensitive to sleep deprivation, higher aspects of cognition were not very affected.

The three discussed hypotheses are not mutually exclusive or incompatible. It could be suggested that the ‘Controlled Attention’ Hypothesis and the ‘Vigilance’ Hypothesis simply take diverse views in explaining the same set of phenomena. And that the ‘Neuropsychological’ Hypothesis, whilst being consistent with the other two models, takes in to consideration the effects above and beyond what may be expected from either. Consequently, certain researchers have suggested a more integrative approach in comprehending the available data. In this regard, Boonstra, Stins, Daffertshofer, and Beek (2007) proposed that impairments in the PFC following a period of sleep deprivation may underlie changes in both executive functioning and attention, highlighting the role of the PFC in the interaction between top-down and bottom-up processes (Lim & Dinges, 2010).

Sleep deprivation can result in various different cognitive and neurobehavioural performance impairments and can result in dangerous situations, such as traffic or work accidents. According to Williamson and Feyer (2002), performing under conditions of sleep deprivation and circadian desynchronisation are often worse than performing under alcohol intoxication. It is therefore imperative that sleep loss and its associated consequences and mechanisms are fully understood in order to minimise reductions in performance and enhance safety (Åkerstedt et al., 2011).

2.4 Consequences of Sleep Loss

Sleep loss can manifest itself in numerous ways. It can have a highly detrimental effect on everyday activities and increase the likelihood of human-error related accidents. Following loss of sleep, individuals often experience difficulties in performing work effectively, carrying out tasks in the home or driving a vehicle safely. It affects everyone to some degree regardless of skill, knowledge or training. Loss of sleep contains an array of consequences such as impairments in behavioural, neurocognitive and psychomotor performance (Alhola & Polo-Kantola, 2007; Banks & Dinges, 2007). Furthermore, cognitive impairments during periods of sleep loss occur as a result of sleep drive with increasing time awake but are also modulated by time of day (as a result of circadian rhythmicity) (Van Dongen & Dinges, 2005). Sleep deprivation research has generally shown that performance reaches a nadir in the early morning hours, typically following 24 hours continuous wakefulness and at the trough of the circadian cycle, before slight improvements are observed as the second day progresses (Caldwell et al., 2003; Caldwell et al., 2004). The improvement in performance rebound on the second day is proposed to occur partly due to the influence of the circadian cycle that rises during the day and also due to the impending completion of the experiment (if in a testing environment) (Previc et al., 2009). However, improvements in performance on the second day do not appear to return to that of rested levels.

2.4.1 Fatigue

Despite the fact that fatigue has been formally studied for over 100 years, there is still no widely accepted scientific theory of its origins and functions (Hockey, 2011). However, according to the Federal Aviation Administration (FAA) fatigue is "a condition characterised by increased discomfort with lessened capacity for work, reduced efficiency of accomplishment, loss of power or capacity to respond to stimulation, and is usually accompanied by a feeling of weariness and tiredness" (Salazar, 2007, pp. 1). Fatigue can be mental or physical in nature and is widely assumed to play a key causal role in reductions in task performance (Hockey, 2013). According to Hockey (2013), fatigue is not a depletion of energy or resources, but rather an adaptive motivational control mechanism. Therefore, in situations in which tasks are of importance, constraints may be overcome by increasing effort, thus allowing the task to be maintained. As task performance continues, fatigue increases as a result of the deployment of increased high effort response. Time on task, heavy workload, circadian disruptions and/or sleep loss can all contibute to mental fatigue and can occur in the presence or absence of each of these variables (Caldwell, 2005; Wesensten et al., 1999). In instances where fatigue arises as a result of time on task or workload, taking a break from the task or switching tasks will aid in the restoration of performance. However, in instances of sleep loss and sleepiness, sleep will be required in order to fully restore performance. For the purpose of this research, fatigue as a result of sleep loss is of particular interest.

Fatigue, as a result of sleep loss and poor sleep quality, is particulary prevalent in those who work irregular schedules or shift workers (Barger et al., 2006). It often presents itself as feelings of tiredness or exhaustion (Kennedy, 1988) and can encompass physiological (i.e., decreased force production), biochemical (i.e., increased cortisol levels), cognitive (i.e., decreased vigilance) and psychological factors (i.e., increased feelings of tiredness) (Wadsworth et al., 2006). Fatigue associated with sleep loss impairs human performance and can have slight or catastrophic effects. From an aviation standpoint, pilot fatigue is predominantly attributed to irregular sleep and work patterns, long flying hours and long waking hours (European Cockpit Association, 2012). In a study by Bourgeois-Bougrine et al., (2003) it was found that both long-haul and short-haul pilots reported feelings of acute fatigue as a result of sleep loss predominantly due to work schedules, night flights, jet-lag and consecutive early wake-ups. According to the International Civil Aviation Organisation (ICAO) crew member fatigue is "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 crew member's alertness and ability to safely operate an aircraft or perform safety related duties" (FRMS, 2011, pp. 1). Fatigue, as a result of sleep loss, has been proposed as a major risk to flight safety (Caldwell et al., 2009; Petrilli et al., 2006b). Findings from accident statistics, reports directly from pilots themselves and operational flight studies indicate that fatigue is a growing concern in the aviation domain (Abeyratne, 2012; Caldwell et al., 2009). The U.S. National Transportation Safety Board (NTSB) have identified fatigue as a major culprit in fatal accidents in commercial aviation operations with pilot fatigue being on the U.S. NTSB's 'Most Wanted List' of safety-related priorities since 1990 (Caldwell, 2005). From a flying performance perspective, as fatigue increases, accuracy and timing decline, attention narrows, decrements in performance are accepted and pilots abilities to integrate information from individual flight instruments into a significant overall pattern decrease (Caldwell & Caldwell, 2003). Lapses in attention or disregard for vital aspects of flight tasks ensue and reductions in ability to efficiently time-share mental resources occur (Caldwell, 2005). However, whether flight safety risk occurs predominantly as a result of decreased general cognitive capacity or as a result of flying-specific factors (e.g., stick control) is yet to be determined (Previc et al., 2009). Whilst both alcohol and drugs can be detected via biochemical tests, fatigue is more difficult to evaluate as a cause of accidents (Griffith & Mahadevan, 2006). Despite the fact that it is not presently overtly detectable, fatigue is increasingly been identified as the primary cause of numerous major accidents.

2.4.2 Mental Health

Sleep loss is associated with an increase in negative mood states (Durmer & Dinges, 2005; Zohar et al., 2005), alterations in emotions (Haack & Mullington, 2005), stress (Bonnet & Arand, 2003), anxiety (Lund et al., 2010) and depression (Rosen et al., 2006). Insufficient sleep has previously been associated with increased risk of psychiatric disorders (Vandeputte & de Weerd, 2003). Moreover, sleep disruption, feelings of fatigue and manifestations of fatigue (e.g., microsleeps) as a result of long working hours have been found to be associated with depression and anxiety (Sirois, Trutschel, Edwards, Sommer, & Golz, 2009). Raggatt (1991) found sleep disturbances among long-distance coach drivers, due most notably from long hours at the wheel (50 hours or more per week), were consistently correlated with stress outcomes. Babson et al., (2010) investigated the effects of acute sleep deprivation on self-reported symptoms of state anxiety and depression as well as general distress among 88 physically and psychologically healthy adults. Results found that following 24 hours' sleep deprivation, state anxiety and depression increased as well as general distress relative to a normal night of sleep. These findings echo those of Babson et al., (2010) who suggest that those who are considered psychologically healthy experience increases in both state symptoms of anxiety and depression, and general distress as a result of sleep loss. Stress can considerably disrupt sleep (as previously discussed above under the 'Stress' sub-heading) however, relatively less is known about the impact of sleep loss on stress responses (Minkle, 2010). Research which employed biomarkers of stress (such as cortisol, interleukin-6, growth hormone) during sleep deprivation studies have provided inconsistent results (Redwine et al., 2000). Despite this, neuroimaging studies support the premise that sleep deprivation is likely to alert subjective and physiological responses to an acute stressor. According to Wang et al., (2005) performance-induced stress is associated with activation in several areas of the PFC (which as already discussed under the 'Neuropsychological Hypothesis' is sensitive to sleep loss) and may function inappropriately when sleep pressure is increased (Durmer & Dinges, 2005). The PFC plays a key role in inhibitory control of negative emotions (Davidson, 2004; Ochsner & Gross, 2005) therefore, impairments in function as a result of sleep loss would be expected to result in dis-inhibited (i.e., more intense) stress responses. As stress is associated with negative affective states such as depression and anxiety (Compare et al., 2014), this enhanced stress response would be proposed to increase the likelihood of developing anxiety and depression.

2.4.3 Microsleep Events

Sleep loss can also result in decreases in latency from wake to sleep onset and microsleep events (Goel et al., 2009). As wakefulness continues, pressure within the brain to fall asleep increases. The transition from wakefulness to sleep is sudden and quick, mimicking an on-off style switch in the brain stem (Schwartz & Roth, 2006). If there is high pressure within the brain to sleep and the individual is highly susceptible to involuntarily falling asleep, this can result in an unsafe situation particulary if engaging in an activity such as driving a car, tending to a patient or operating an aircraft. Furthermore, individuals are also susceptible to involuntary microsleep events. A microsleep event is an unexpected brief episode of sleep which lasts anything between 1 to 30 seconds and occurs in the midst of ongoing wakeful activity (Moore-Ede et al., 2004). Initial microsleeps are relatively brief, however, as fatigue increases, these events become longer (Tirunahari et al., 2013). Furthermore, the more sleep deprived one is, the more frequent microsleep events become (Ong et al., 2015). During microsleeps, whilst an individual can appear awake, their brain will not process information, lapses in attention occur and one's ability to detect and respond to crucial stimuli and events is impaired (Boyle et al., 2008). During active tasks, microsleeps manifest as a complete failure to respond and is concomitant with slow eyelid-closure, droopy eyes, blank stares and head nodding (Peiris et al., 2006). Operators are often unaware of their level of impairment due to fatigue and are unable to identify the early symptoms of microsleep events. Whilst microsleep events are typically associated with a reduction in responsiveness to the external environment, it is less known what occurs in the brain during these brief moments from drowsiness to light sleep however, reduced activity in the thalamus, the region of the brain involved in sleep regulation and also in relaying sensory and motor signals to other parts of the brain, has been observed (Ong et al., 2015). Furthermore, other areas of the brain such as the frontal parietal lobe, which is responsible for sensory processing and paying attention, have shown increased activity potentially as a result of the brains attempt (and failure) to remain awake. This suggests that various regions of the brain may be in 'waking' mode whilst others temporarily surrender to sleep (Ong et al., 2015). These momentary lapses in attention are particularly concerning especially in occupations such as flying where public safety is dependent on prolonged vigilance and high level performances by pilots.

2.4.4 Performance in the Workplace

The adverse consequences of sleep loss have been demonstrated both in experimental settings and in real-life situations (Otmani et al., 2005; Philibert 2005; Russo et al., 2005). Various studies have investigated the impact of sleep loss in specific occupations in certain professions such as doctors (Wali et al., 2013), nurses (Lockley, 2007), commercial drivers (Pack et al., 2006), miners (Ferguson et al., 2011), the maritime industry (Wadsworth et al., 2006), offshore drilling crews (Sneddon, Mearns & Flin, 2013), and naval officers (Olsen, Pallesen & Espevik, 2013). In a study conducted by Bloomfield, Harder and Chihak (2009), 20 commercial motor vehicle drivers were subjected to 20 hours sleep deprivation. Participants drove a fixed-base advanced driving simulator for approximately one hour on four occasions (09:00; 15:00; 21:00; 03:00). The driving test route consisted of overpasses, intersections and changes in speed limits. Results found that vehicle drivers steering performance was significantly impaired following 18 hours continuous wakefulness whilst driving speed increased following 12 hours continuous wakefulness. Working in sleep deprived situations increases fatigue and the risk of making professional errors (Lockley et al., 2007). Furthermore, in research conducted by Grantcharov and colleagues (2001), it was found that surgeons-in-training who experienced sleep restriction took significantly more time to complete a virtual laparoscopic surgery, made significantly more errors and had significantly more unnecessary movements during the surgery task. However, according to Deaconson et al., (1988), sleep restriction (less than 4 hours of continuous sleep in the preceding 24 hours) did not affect the overall cognitive or motor performance of surgical residents. It has been suggested that outcomes in the surgical literature is conflicting regarding the link between sleep loss and surgical errors (Sugden et al., 2012). Lack of control data, poor methodologies, and inappropriately defined sleep loss criteria can cause inconsistent findings resulting in unclear outcomes of the true effects of sleep loss on performance (Connor et al., 2001).

2.4.5 Incidents and Accidents

Sleep loss among workers, particularly in 24 hour operations, can have very serious consequences. The nursing, medical, mining, maritime, transport, automobile and aviation industries are all susceptible to sleep loss and tragically, loss of sleep has been implicated in several catastrophic incidents and accidents. In the transport industry, best estimates propose that fatigue and sleep loss contribute to about 15 – 20% of truck accidents. However, official statistics are proposed to contain lower estimates due to under-reporting of driver fatigue or sleep in accident reports (Amundsen & Sagberg, 2003). The impact of fatigue and sleep loss and its negative and sometimes calamitous effects are particularly evident within the aviation industry with previous events highlighting the detrimental impact of these. In 2004, Corporate Airlines Flight 5966 crashed on its approach to Kirksville Regional Airport killing 11 of its 13 passengers and 2 crew. The fatigued pilots, who were on their sixth flight of the day, had been on duty for 14 hours (Caldwell, 2012). Additionally, fatigue and sleep loss resulting from long duty periods and/or circadian factors was implicated in the Korean Air flight 801 crash in which 228 people died (NTSB Aircraft Accident Report, 1999). Moreover, in February 2008, although eventually landing safely, Go! Airline Flight 1002 overshot their destination by more than 30 miles after both pilots fell asleep on the flight deck, despite the trip only being 50 minutes long. Furthermore, in October 2009 during a routine scheduled flight from San Diego to Minneapolis, the pilots in control of Northwest Airlines Flight 188 did not respond to communications from air traffic control for nearly 90 minutes and overflew their destination by 150 miles as a result of dozing off in the cockpit (Caldwell, 2012). The magnitude of sleep and fatigue-related accidents demonstrates the necessity to create adequate preventative and protective measures that alleviate errors caused by sleep loss and associated fatigue (Costa, 2003).

2.5 Sleep and the Aviation Industry

The stakes in aviation differ from that of other transport operations due to the involvement of multimillion-dollar airframes and the lives of up to 555 passengers (Caldwell, 2012). A single major civil aviation accident can have major financial losses (in exceedance of $500 million (~€384) in total), inestimable personal suffering and a calamitous mishap on airline revenues (Caldwell, 2005). Despite the high risks at stake, the commercial aviation industry has received relatively limited attention as regards the impact of sleep loss and associated fatigue. Not only are commercial airline pilots subjected to highly demanding, complex and stressful environments but they typically operate long working shift-work hours. Whilst there have been considerable advancements in aviation technology and operational demands, the human operators need for sleep remains. Air traffic around the world has doubled every 10 years for the last 30 years (Reis, Mestre & Canhao, 2013). As a result, today's flight operations now work on a pressurised 24/7 timetable and as such, so to do pilots. The unrelenting escalation in international long-haul, short-haul, regional and overnight operations will continue to increase these round-the-clock requirements (Åkerstedt et al., 2003). According to Caldwell et al., (2004), flight skills, despite being well-practiced with hundreds of hours' training, are susceptible to the effects sleep deprivation.

2.5.1 Medium-/Short-Haul vs Long-Haul

There are two different types of flights: medium-/short-haul and long-haul flights. Medium-/short-haul operations are typically classified as being less than 6 hours in duration with several sectors in a single duty period. Long-haul operations last 6+ hours usually with one or two sectors maximum. Long-haul pilots who operate extended trans-meridian sectors have been well researched and reviewed (Harris et al., 2001). According to Powell, Spencer, and Petrie (2011), long-haul pilots report higher ratings of fatigue relative to those for short-haul flights. However, according to Reis, Mestre and Canhao (2013), those who fly medium-/short haul present with higher levels of total mental fatigue. Medium-/short-haul pilots have been less well studied despite the fact that it has been identified that fatigue in each type of operation differs considerably (Jackson & Earl, 2006). Short-haul pilots have tended to be neglected in studies of fatigue, sleep loss and circadian disruption which have occurred as a result of flight operations (Jackson & Earl, 2006). It is possible that the flight duty time legislation, which is predominantly based from long-haul operations, may be inadequate to successfully protect against the occurrence of potentially dangerous levels of fatigue in short-haul pilots. Anecdotal evidence from pilots suggest that, as a result of the increasing demand of low-cost air travel, short-haul commercial airline pilots may be becoming seriously sleep deprived and fatigued. Furthermore, medium-/short-haul operators may be subjected to long duty days, short night-time stopovers and shorter sleeping periods as a result of the competitive short-haul industry which further exacerbates flight crews sleep loss and fatigue (Previc et al., 2009). The NTSB indicated growing concern over long working hours for those operating medium-/short-haul operations stating that it was recognised that fatigued pilots operating up to 19 hours continuous wakefulness were more prone to making errors of judgement in tactical decision-making. The present research will solely focus on medium-/short-haul pilots.

2.5.2 Flight Time Limitations

Since the Chicago Convention in 1944 (also referred to as the Convention on International Civil Aviation), pilot fatigue was recognised as posing a risk to the safety of air operations. In a European context, this risk is addressed at two levels: (i) through EU-wide binding Flight Time Limitation (FTL) rules and (ii) at company level via sound rostering practices, Collective Labour Agreements, and/or Fatigue Risk Management Systems (FRMS). For the purpose of this research, main focus will be placed on FLT's. The current Flight Time Limitations (FTL's) at the time of this research, set out by the European Aviation Safety Agency (EASA), first came into effect in July 2008 and remained in place until February 2016. These legally binding minimum set of FTL safety rules, contained within the European regulations on Air Operations (EU-OPS) – subpart Q, are purported to prevent pilot fatigue across Europe.

Although positive in their purpose, these FTL regulations are not based on sound scientific evidence regarding their ability to prevent pilot fatigue (Moebus, 2008). In 2010, the Norwegian Airline Pilots Association (NRK) conducted a survey investigating pilots experiences working under the current regulations. Results from the survey of 389 pilots found that 5.2% (yes, once), 65.2% (yes, now and then/rarely) and 17.7% (yes, often) of pilots indicated that they felt so tired or fatigued that they should not be on active duty in the cockpit. In 2011, the Danish Airline Pilots Association (DALPA) conducted a similar survey. Results from the survey of 601 pilots found that 9% (yes, once), 57% (yes, now and then/rarely) and 23% (yes, often) reported that the felt so tired or fatigued they felt they should not be on active duty in the cockpit. Furthermore, in 2011 a survey conducted on 625 pilots by the Swedish Airline Pilots Association (SWALPA) indicated that 8% (yes, once), 60% (yes, now and then/rarely) and 26% (yes, often) indicated that they felt so tired or fatigued that they should not be on active duty in the cockpit. Moreover, findings from the SWALPA survey found that the current regulations were considered a high (44%) or very high (38%) safety risk as they contribute to a lack of proper rest and sleep. These findings suggest that loss of sleep and fatigue among European pilots is a very serious problem. In 2012, the European Cockpit Association (ECA) produced a 'Pilot Fatigue Barometer' to investigate the prevalence of fatigue in Europe's cockpits. This report analysed several surveys on pilot fatigue conducted by member associations – Norway, Denmark, UK, Germany, Sweden, France, Austria and The Netherlands. These surveys were conducted between 2010 and 2012 and involved more than 6,000 pilots. Results concluded fatigue among European pilots to be a highly prevalent and under-reported safety issue with over 50% of those surveyed reporting experiencing fatigue levels which they found to impair their abilities while on flight duty. According to the report by the ECA (2012), insufficient rest and sleep opportunities, shiftwork and long duty hours make pilots particulary prone to fatigue.

In February 2016, a newly modified set of FTL's were implemented across Europe. Some of the amendments from the original regulations included a reduction in the maximum flight duty time at night (defined as 02:00 – 04:59) from 11:45 to 11 hours; a decrease in maximum number of flying hours per year (12 consecutive months) from 1,300 to 1,000 hours and; maximum duty time during airport standby (i.e., standby + flight time) is fixed at 16 hours as opposed to the 26 or 28 hours permitted by some member states. The maximum daily flight duty period remained unchanged at 13 hours per duty whilst commanders discretion also remained unchanged (2 hours if flight crew are not augmented; 3 hours if flight crew are augmented). The European Parliament decided not to follow the advice of its transport committee, which had rejected the European Commission's draft law on FTL's after safety concerns were raised, and voted in favour of the new regulations. However, the ECA, who represent pilots from all over Europe expressed concern over the outcome. According to the secretary general of the ECA – Philip von Schöppenthau – "the text approved still contains significant safety loopholes…..as long as scientific recommendations are deliberately ignored, the whole package remains unsafe. This text has been tailored around the airlines' commercial needs, not around passenger safety" (Milevska, 2013). These findings suggest that despite the implementation of these new amendments, confusion and disparity still prevail.

2.5.3 Sleep Loss and Pilot Performance

Research investigating sleep loss and fatigue in commercial aviation has been conducted by applying different methodologies such as in-flight or using simulators. Some studies have employed laboratory-style tasks (e.g. Psychomotor Vigilance Task (PVT)) whilst others have utilised surveys only. One study by Goode (2003) looked at accident data. However, overall a relatively limited number of studies have investigated the impact of sleep loss and fatigue on commercial airline pilots (Caldwell et al., 2004; Lopez et al., 2012; 1999; Previc et al., 2009; Russo et al., 2005). Excluding surveys, in the last 20 years, to the knowledge of the researchers, only 12 published studies in total were found which looked at the effects of sleep loss and fatigue among commercial airline pilots[1]. Table 2.1 contains an overview of these key research studies conducted to date which examined the effects of sleep loss and fatigue among commercial airline pilots. (Survey only studies were not included in Table 2.1).

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[1] *A literature search was conducted utilising the terms 'sleep', 'fatigue', and 'sleep loss' combined with commercial aviation and pilot to focus on sleep and fatigue research among commercial airline pilots. The databases searched included Google Scholar, PubMed, Web of Knowledge and Science Direct. Cited references within published research were also investigated. The search was confined to within the last 20 years. The search covered a period through April 1, 2018.*

Table 2.1: Summary of prior research investigating the effects of sleep loss and fatigue among commercial airline pilots.

Data Collection Method	Author	Participants	Independent Variable	Dependent Variable	Results
In Flight	Powell, Spencer, Holland, Broadbent, & Petrie, 2007	1,370 ratings from Air New Zealand Boeing 737 pilots	Number of sectors flown Length of duty period Time of duty period	Samn-Perelli Fatigue Rating prior to descent at the end of each short-haul duty	Increased with increased sectors Increased with longer duty Weaker influence. Lower levels at mid-day, increased later in day
In Flight	Powell, Spencer, Holland, & Petrie, 2008	3,023 ratings from Air New Zealand two-pilot operations ranging from 3 – 12 hours	Time of duty period Length of duty period Number of sectors	Samn-Perelli Fatigue Rating prior to descent at the end of each short-haul duty	Highest in window of circadian low (02:00 – 06:00); lowest in early evening Increased with longer duty Higher following 2 vs 1 sector
In Flight	Powell, Spencer, & Petrie, 2010	24 Boeing 737 pilots with no layover; 21 A320 pilots with no layover; 27 Boeing 737 pilots with one or two day layover	Trip time Type of aircraft Layovers Outbound versus return flight	Samn-Perelli Fatigue Rating, Visual Analogue Fatigue Scale & Karolinska Sleepiness Scale after top of climb, mid-cruise, and prior to top of descent Reaction Time Task	Increased over trip time for all three groups Increased less on the A320 flight than on the Boeing 737 flights No effect Increased more on return flight than on the outbound flight
In Flight	Powell, Spencer, & Petrie, 2011	4,629 ratings from Boeing 777 pilots	Long-haul flights versus short-haul flights Return versus outbound flight Overnight versus daytime flight	Samn-Perelli Fatigue Rating prior to descent at the end of short-haul and long-haul flights	Higher on long-haul flights Higher for short-haul flights on return than at the end of their outbound flight Higher for overnight flights
In Flight	Roach et al., 2011	301 pilots flying long-haul	Length of duty time	Amount of sleep during duty period (in-flight napping) Rest time	Significant positive correlation More likely to sleep when duty periods were longer

Data Collection Method	Author	Participants	Independent Variable	Dependent Variable	Results
In Flight	Roach et al., 2011	301 pilots flying long-haul	Length of duty time	Amount of sleep during duty period (in-flight napping)	Significant positive correlation
				Rest time	More likely to sleep when duty periods were longer
In Flight	Drury et al., 2012	Two-person airline crews during 302 normal flight sectors	Captain versus First Officer	15 trained observers identified periods of heightened emotional activity (e.g. confusion, frustration, stress)	Higher frequencies of [confusion and stress for captains] and [confusion and frustration for first officers] who reported < 5 hours' sleep in the last 24 hours
In Flight	Vejvoda et al., 2014	40 commercial short-haul pilots (15 Captains; 25 First Officers)	Time of duty period	Samn-Perelli Fatigue Rating and Karolinska Sleepiness Scale at the end of each flight and each flight duty period	Pilots on late-finishing duty periods were awake longer by an average of 5.5 hours versus early morning starts
Laboratory -Based	Neri et al., 2002	14 two-person crews flew a 6 hour flight in a Boeing 747-400 simulator	18 to 20 hours continuous wakefulness	PVT Performance	Worst performance recorded between 05:50 and 06:50
In Flight (Using Laboratory Tasks)	Petrilli, et al., 2006a	19 pilots flying international flight	5 minutes before and after a flight	Samn-Perelli Fatigue Rating	Significantly higher at the end of flights
				PVT mean response speed	Significantly slower at the end of flights
Simulator	Petrilli, et al., 2006b	134 pilots divided into 67 crews, each with one captain and one first officer	At least four consecutive days of free duty (rested) or immediately following the final landing at the end of an international flight (not rested)	Threat and error detection during a 70-minute flight in a B747-400 simulator	No significant effect of rested and not rested crews on threat detection
				Errors during a 70-minute flight in a B747-400 simulator	Significantly more errors (40.3%) with < 5 hours of sleep in last 24 hours versus > 5 hours (26.0%)
					44.3% of errors detected by a rested crew versus 56.9% by non-rested crew
Accident Analysis	Goode, 2003	Air carrier accidents from 1978 to 1999	Duty hours	Accident proportion	Increased with longer duty hours

Previous research among commercial pilots have reported that sleep loss and fatigue result in extreme feelings of fatigue (Bennett, 2012), declines in attention and vigilance (Neri et al., 2002), increases in confusion, stress and frustration (Drury et al., 2012) and increased errors in the cockpit (Petrilli et al., 2006b). However, to the knowledge of the authors, no previous research have investigated the effects of sleep loss and fatigue on commercial aviation flying-specific performance parameters, as has been conducted in military aviation (Lopez et al., 2012; Previc et al., 2009). Furthermore, some of the sleep loss and fatigue research has tended to focus on cognitive processes which have little ecological validity as they do not reflected the true nature of the particular job or normal working duties (e.g., serial reaction time). Sometimes, the overall picture can lead to confusion with certain clinical skills indicating no impairments whilst simultaneously some psychological tasks showing deteriorations in performance which are of no known relevance to this or other occupation-specific skills (Harrison & Horne, 2000). It is therefore important that the research measures and employs tasks and competencies that are of real-world relevance and are specifically applicable to the occupation under investigation.

2.6 Core Pilot Competencies

Prior to investigating the impact of sleep loss and fatigue on commercial pilots, it is vital to first identify the key competencies required by commercial pilots in order to successfully and safely operate an aircraft. The International Civil Aviation Organisation's (ICAO) manual of evidence-based training, identified 8 core competencies which are proposed to encompass the technical and non-technical knowledge, skills and attitudes to operate safely, effectively and efficiently in a commercial air transport environment. These core competencies are defined as "a group of related behaviours, based on job requirements, which describe how to effectively perform a job and what proficient performance looks like" (ICAO Manual, 2013, pp. xi) (See Table 2.2). In summary they are: 1. Application of Procedures, 2. Communication, 3. Aircraft Flight Path Management – Automation, 4. Aircraft Flight Path Management – Manual Control, 5. Leadership and Teamwork, 6. Problem Solving and Decision Making, 7. Situation Awareness and 8. Workload Management. (Please see the 2013 ICAO Manual of Evidence-Based Practice for a more detailed explanation of each competency).

Table 2.2: A complete outline of competencies, competency descriptions and related behavioural indicators, encompassing the technical and non-technical knowledge, skills and attitudes to operate safely, effectively and efficiently in a commercial air transport environment – 2013 ICAO Manual of Evidence-Based Practice.

Competency	Competency Description
Application of Procedures	Identifies and applies procedures in accordance with published operating instructions and applicable regulations, using the appropriate knowledge
Communication	Demonstrates effective oral, non-verbal and written communications, in normal and non-normal situations
Aircraft Flight Path Management, automation	Controls the aircraft flight path through automation, including appropriate use of flight management system(s) and guidance
Aircraft Flight Path Management, manual control	Controls the aircraft flight path through manual flight, including appropriate use of flight management system(s) and flight guidance systems
Leadership and Teamwork	Demonstrates effective leadership and team working
Problem Solving and Decision-Making	Accurately identifies risks and resolves problems. Uses the appropriate decision-making processes
Situation Awareness	Perceives and comprehends all of the relevant information available and anticipates what could happen that may affect the operation
Workload Management	Manages available resources efficiently to prioritise and perform tasks in a timely manner under all circumstances

In an attempt to define pilot competencies which may be sensitive to fatigue, researchers at the Netherlands Institute for Neuroscience (NIN) and the National Aerospace Laboratory (NLR) in Amsterdam, reviewed 19 National Transportation Safety Bureau (NTSB) investigation reports of accidents and incidents involving flight crew fatigue. The results can be seen in Figure 2.2. 'Problem Solving and Decision Making', 'Workload Management', 'Situation Awareness' and 'Leadership and Teamwork' were identified as those most mentioned in the review of the 19 NTSB investigation reports of accidents and incidents involving flight crew fatigue and as such are purported to potentially be sensitive to fatigue.

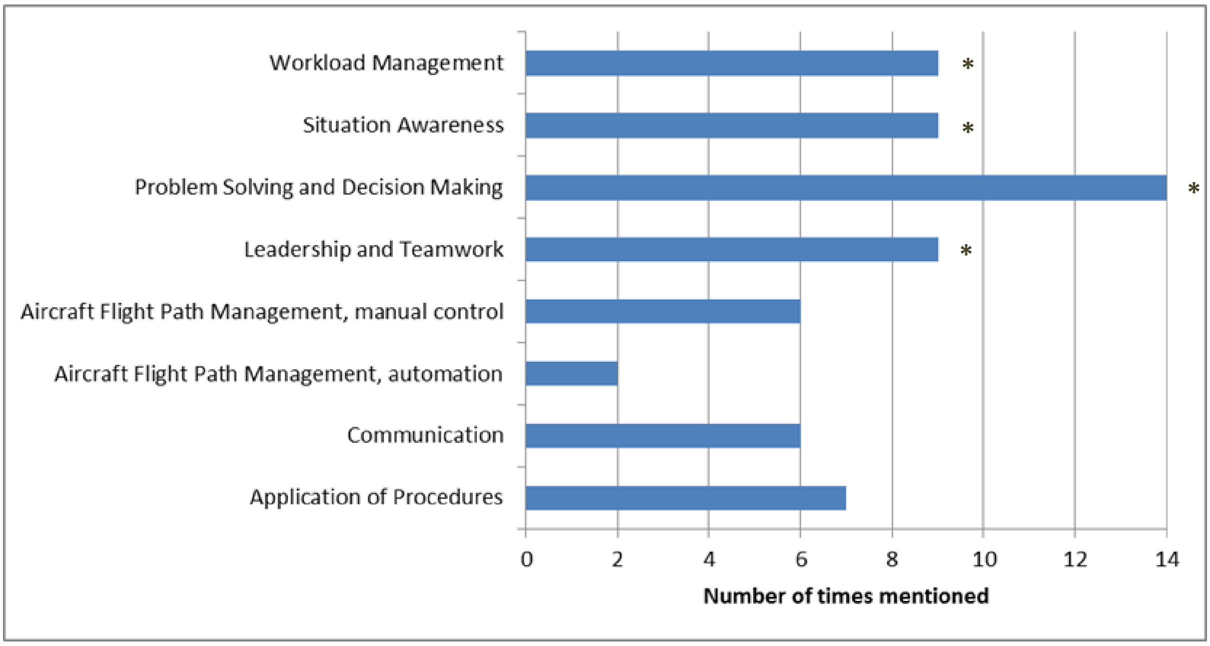

Figure 2.2. Review of 19 National Transportation Safety Bureau (NTSB) investigation reports of accidents and incidents involving flight crew fatigue.

Following further examination of the scientific literature, discussions with researchers in the NIN and NLR, and various commercial airline pilots, this research predominantly focused on problem solving and decision-making, workload management, and situation awareness. Taking into consideration the nature and set-up of this particular research study, leadership and teamwork were deemed unfeasible to investigate in this instance.

2.6.1 Problem Solving & Decision-Making

According to the ICAO manual, problem solving and decision-making are described as the ability to accurately identify risks and resolve problems as well as use appropriate decision-making processes. Pilots must be able to quickly and effectively detect deviation from the desired flight path, evaluate problems, identify risks, consider alternatives and select the best course of action whilst continuously reviewing progress and adjusting plans accordingly (ICAO Manual, 2013). Pilots are often required to innovatively respond to unique problems, novel task demands and make timely and correct decisions in chaotic situations (Adams, 1993). For example, a pilot may experience a fuel leak, jammed landing gear or emergency medical issues with passengers on-board. Expert pilots must be able to revise and review various problems and determine several possible interpretations of the situation (Adams, 1993). Furthermore, they must also be able to monitor, review and adapt decisions as required, all while working through problems without reducing safety.

Loss of sleep has been suggested to impair problem solving, decision-making and one's ability to revise plans which can be of particular concern especially in emergency situations when these skills would be required (Curcio, Ferrara & Gennaro, 2006). Problem solving and decision-making are higher-order processes which fall under executive functions (Hughes et al., 2005). Executive functions occur as a result of a coordinated operation of numerous neural systems and are a necessary requirement for multiple cognitive functions (such as problem solving and decision-making) (Funahashi & Andreau, 2013). The PFC, located in the frontal lobe of the brain, is considered the key structure for the performance of executive functions and is associated with decision-making, maintaining attention while ignoring distractions, logical reasoning, initiating goal-directed behaviour and planning (Funahashi & Andreau, 2013; Grugle, 2005). Any damage to the PFC is often found to result in impairments in decision-making. Research investigating the effects of sleep deprivation on the PFC found results similar to that of individuals with frontal lobe damage (Grugle, 2005). Several human-based studies have found the neural systems of the PFC involved in executive functioning to be particularly susceptible to sleep deprivation (Durmer & Dinges, 2005) which coincides with the 'Neuropsychological Hypothesis' discussed above. As a result, multiple neurocognitive functions are negatively impacted by acute sleep loss, such as attention and divergent thinking (Alhola & Polo-Kantola, 2007), decision-making (Kilgore, Balkin & Wesensten, 2006), memory, and response inhibition (Meerlo et al., 2009). Furthermore, these findings have been confirmed by neuroimaging studies (e.g. Drummond et al., 1999, 2000; Goel et al., 2009). Nonetheless, Binks, Waters & Hurry (1999), found that short-term sleep deprivation does not selectively impair prefrontal functioning. However, all tests employed by Binks and colleagues were taken from a neuropsychological test battery which was designed for clinical purposes mainly to assess brain damage. Therefore, the tests may have contained a ceiling effect which was not sufficiently sensitive to the effects of short-term sleep deprivation particularly for use among university level students (Harrison & Horne, 2000).

2.6.2 Workload Management

Workload management refers to the ability to manage available resources efficiently and to prioritise and perform tasks in a timely manner under all circumstances (ICAO Manual, 2013). Pilots must be able to prioritise and receive assistance to maximise focus on the task as well as continuously monitor flight progress (ICAO Manual, 2013). During flight, pilots are required to conduct numerous tasks safely, effectively and efficiently. For example, pilots must manage the status of the aircraft system and anticipate future tasks as well as conduct primary tasks such as flying, navigation and communications (Lee, 2010). Workload for pilots varies depending on the phase of the flight (e.g., take-off, cruise, landing) (Lee, 2010). During certain phases of flight, workload is increased as specific tasks need to be performed (e.g., for final approach to landing – setting the flaps and landing gear, maintaining airspeed, tracking glide path) (Lee, 2010).

Despite the increasing interest in the concept of workload in the last 40 years, like fatigue, workload still has no clearly defined, universally accepted definition (Cain, 2007). According to resource or capacity models of mental workload, there is a limited amount of resources available to undertake a task, and in order to perform that task, some or all of the resources must be utilised. These models of workload address the difference between the amount of resources required by the task situation and the amount of resources available within a person (McCloy, Derrick & Wickens, 1983). The notion of capacity arises from studies of overload of attention in which performance declines seemingly because the processing system is unable to deal with all the information it is presented with (Mathews, Davies, Westerman & Stammers, 2000). A relatively limited amount of focus has been devoted to understanding the impact of modest sleep loss on task performance and simultaneous mental workload (Tomasko et al., 2012). According to Morris and Miller (1996), sleep restriction (2.4 hours' sleep the previous night) resulted in significant increases in subjective workload among 10 military pilots during a simulated flight. Interestingly, Tomasko et al., (2012) found that moderately sleep deprived medical students indicated no differences in their ability to perform a previously learned simulated surgical task or to learn a new simulated surgical task. However, in order to obtain the same level of performance, those who were deprived of sleep indicated a greater cognitive workload in comparison to their rested counterparts. Greater workloads have been found to be associated with more errors (Zheng et al., 2010). In support of this, Yurko et al., (2010) found that higher cognitive workload was associated with more errors during a laparoscopic simulator task. The literature seems to suggest that while actual workload may be the same, one's perception of cognitive workload increases under conditions of sleep deprivation, which is associated with an increased likelihood of making an error. Furthermore, according to Cain (2007), an operators abilities as well as their effort moderate the workload experienced by the operator. Loss of sleep is proposed to result in sleepiness, interfere with arousal mechanisms and decrease the supply of energy required to power arousal, perceptual processes, motivation and effort. This deficit in arousal decreases the desire to perform, reduces effort and may contribute to an operator's enhanced perception of their cognitive workload (Xie et al., 2013).

2.6.3 Situation Awareness

Maintaining awareness of the work environment, comprehending the information it holds and predicting how the situation will develop are some of the critical factors in the prevention of industrial accidents (Stanton et al., 2001). Situation awareness is the ability to perceive and comprehend all relevant information available and anticipate what could happen that may affect the operation, according to the ICAO manual (2013). Pilots need to have an awareness of the aircraft state in its environment and be able to project and anticipate changes (ICAO Manual, 2013). It is considered a critical criterion for the safe and effective operation of complex dynamic systems such as an aircraft (Salmon, Walker & Stanton, 2016). Pilots are required to monitor the environment and situation relative to the planned sequence of events during a flight (Salmon, Walker & Stanton, 2016).

Loss of situational awareness manifests itself in the operator as the failure to continue responding appropriately or even in responding to the situation completely inappropriately. According to Caldwell et al., (2004) sleep loss and fatigue result in poor situational awareness (Caldwell et al., 2004; Tucker et al., 2010). Decreased situational awareness has been identified as a causal factor in several aviation mishaps (Salmon, Walker & Stanton, 2016). However, in a study by Stratton, Furey and Hogan (2014), one night of sleep deprivation did not affect residents situational awareness in a trauma simulation although the authors concluded that more research was needed. Whilst the cognitive processes that support situation awareness are not well understood (Juarez-Espinosa & Gonzalez, 2004), research has identified that cognitive components such as attention, perception and working memory contribute to its functioning which are associated with the PFC in the frontal lobe of the brain

(Alhola & Polo-Kantola, 2007). As previously mentioned, the PFC is highly sensitive to loss of sleep suggesting that these components are susceptible to reductions in functioning during periods of sleep deprivation. Furthermore, prefrontal damage or disorders of attention and perception involve a reduction in awareness of the environment, sensory neglect, a decline in general awareness of the environment, reduced sustained attention and a decline in concentration (Alhola & Polo-Kantola, 2007; Lim & Dinges, 2010). Additionally, according to Harrison and Horne (2000), situations which require avoidance of distraction, risk assessment, and awareness for what is feasible are behaviours which are proposed to be particularly vulnerable to sleep deprivation, both when working alone and as part of a team. The influence of sleep deprivation on these behaviours is purported to be particularly significant in situations which quickly change and in which operators need to adapt to a wide range of incessant and unpredictable developments (Harrison & Horne, 2000).

2.6.4 Method of Measurement – Sleep Deprivation

A majority of studies which have examined the impact of sleep deprivation on behaviour and psychological performance have utilised measures which are deemed sensitive to sleepiness, preferring more basic skills such as vigilance, reaction time and components of memory (Lim & Dinges, 2010). These tasks are often monotonous and lack environmental stimulation which can actually produce optimal conditions to maximise the negative effects of sleep deprivation thus potentially masking true results (Harrison & Horne, 2000). Furthermore, the monotonous aspect of these tasks is further facilitated by the need to ensure that participants are well trained in task procedures in advance to curtail practice effects (Harrison & Horne, 2000). Tests which lack novelty and are tedious will begin to show reductions in performance earlier during periods of sleep deprivation (Lim & Dinges, 2010). Furthermore, tests which form part of a much longer battery of similarly monotonous tests only serve to further increase this tedium (Harrison & Horne, 2000). At present it remains somewhat unclear from the literature whether tasks related to cognitive speed, visual and auditory attention and psychomotor skills are sensitive to one night of sleep deprivation as a result of a decline in these cognitive functions or as a result of monotonous tasks which lack novelty.

Tasks which are too interesting, too complex, too variable and especially too short, should not be used to measure the effects of sleep deprivation (Alhola & Polo-Kantola, 2007). It has been suggested that tasks which satisfy this criteria intrinsically encourage sleep deprived individuals to apply compensatory effort and perform normally and as such these tasks are insensitive to sleep deprivation. Likewise, when employing dull, monotonous, reaction-time and vigilance tasks, if participants are encouraged to invest more effort, for example, such as by giving them knowledge of results or financial rewards, then these tasks will lose their sensitivity to sleep loss (Harrison & Horne, 2000). Tasks which are complex, essentially rule-based and interesting will not be sensitive to sleep deprivation. However, if these tasks are administered many times to the participant, they will become well learned, may lose their novelty and risk becoming dull and monotonous which will influence their sensitivity to sleep loss, unless they are re-motivated to perform well. The prevalent view in the sleep deprivation literature is that high level complex skills remain relatively unaffected by sleep deprivation due to the interest and inherent encouragement they generate resulting in participants applying compensatory effort to overcome sleepiness (Harrison & Horne, 2000).

A further matter to debate is the extent to which these more conservative laboratory-based tasks are ecologically valid in terms of how they relate to real-world scenarios. Various sleep loss literature exists which has little relevance to the particular occupation under investigation. This can result in conflicting findings with limited application. Furthermore, Connor et al. (2001) concluded that lack of control data, poor methodologies, and inappropriately defined sleep loss criteria provide no clear conclusions, despite the large volume of studies. For example, some sleep loss results are compared with off-duty days when the participant is still recovering from the effects of long work hours and performance is still diminished. Therefore, it is likely that the effects of sleep deprivation are often misrepresented and provide limited insight into performance during actual real-world scenarios. Possibly one of the only consistent findings is regarding the effects of sleep deprivation on mood. However, the relationship between mood and performance remains speculative (Harrison & Horne, 2000).

2.6.5 Method of Measurement – Fatigue

Individuals are not good assessors of their own momentary fatigue levels, which is reported to become increasingly difficult to detect the more tired one becomes (Williamson & Chamberlin, 2005). Therefore, some additional measure/s need to be implemented which will detect and inform individuals of their fatigue levels. At present, no known ‘gold standard’ or threshold exists which can determine that an individual is too fatigued to work/continue working. However, there is considerable interest and movement towards the extensive use of fatigue systems which may (or may not) detect fatigue (Dinges & Mallis, 1998). A significant issue regarding fatigue measurement is the limited number of direct measures, with most focusing on fatigue outcomes as opposed to fatigue itself. Self-report may be the only direct measure of fatigue however, due to the influence of demand effects and motivational influences, this is not a reliable measure (Williamson & Chamberlin, 2005). Over the past 10 years, extensive effort has been invested in to the development of sleepiness and performance measures which warn individuals of fatigue impairments (Barr et al., 2009). Early identification and warning of increasing fatigue levels may reduce the likelihood of potential incidents and accidents (Williamson & Chamberlin, 2005). According to Heitmann et al., (2001) at present, the technology is expensive and its reliability is insufficient for widespread distribution. Multiple studies have demonstrated significant impairments in performance on basic cognitive tasks in fatigued individuals (Alhola & Polo-Kantola, 2007) thus suggesting there may be great potential for employing such tasks to predict when a fatigued individual may be susceptible to performance degradations on real-world tasks such as flying an aircraft (Lopez et al., 2012). However, the degree to which simple cognitive tasks can be utilised to predict performance decrements on real-world tasks remains unclear.

2.7 Summary

The advancements in aviation technology and operational demands as well as the increase in today's commercial flight operations have resulted in a 24/7 commercial aviation industry. Dublin airport alone handled 27.9 million passengers in 2016, averaging 541 flights every day. This equates to a pilot taking off or landing in Dublin airport every 2 minutes (Dublin Airport, 2017). With +100 passengers per flight, any mistake or error could prove catastrophic. European medium-/short-haul commercial airline pilots are presently highly susceptible to sleep loss and fatigue with several pilot surveys suggesting this is presently the case (DALPA, 2011; NRK, 2010; SWALPA, 2011). However, no such research has ever been conducted in an Irish context despite being home to Europe's largest low cost airline and is proposed to have in excess of 3,000 commercial airline pilots, one of the largest of any European state. Sleep loss and fatigue result in impairments in cognitive parameters (Caldwell et al., 2004) and flight performance (Caldwell, Caldwell & Darlington, 2003). However, whether declines in flight safety occur as a result of decreased general cognitive capacity or due to flying-specific factors (e.g., stick control) is yet to be determined (Previc et al., 2009). Whilst the effects of sleep loss and fatigue on performance in laboratory-based tasks have been examined (Gawron, 2014), inconsistent findings are still emerging in these controlled conditions. These discrepancies are exacerbated in real-world conditions. More work is required to identify which components of performance are reliably degraded by loss of sleep and fatigue (Kilgore, 2010). Substantial gaps in the knowledge of sleep loss and fatigue still exist, particularly in the aviation domain (Gawron, 2016). Many questions remain unanswered, such as what are the attitudes and experiences of Irish-registered commercial airline pilots to sleep loss and fatigue working under the current Flight Time Limitations? And, how do these factors influence flight safety, pilot mental health and performance in the cockpit? Therefore, the present study aimed 1) to examine the influence of sleep loss and fatigue on incidents in flight and pilot mental health and 2) investigate the effects of sleep deprivation and fatigue on commercial airline pilots' core competencies and flying performance. According to Lopez et al., (2012) the number of serious accidents occurring as a result of operator fatigue appears to be on the increase. Identifying and mitigating sleep loss and fatigue among commercial airline pilots will aid in promoting pilot mental health and well-being and enhance flight and passenger safety.

Figure 2.3 contains a flow diagram of this research project. To begin, following discussions with members of the Irish Airline Pilots' Association and an in-depth review of the scientific literature, it was concluded that sleep loss and fatigue were proposed to be a threat to commercial airline pilot performance within Irish cockpits. This research project consisted of four studies – the first two studies were survey-based and subjective (each from the same survey data) whilst the second two studies were experiment-based and objective (with the first study acting as a pilot study for the final study). Therefore, this research initially wanted to explore if sleep loss and fatigue, as a result of the current regulations, influence pilot performance and well-being. This was addressed in Study 1 and Study 2. On conclusion that sleep loss and fatigue, as a result of the current regulations, was found to influence incidents in flight and pilots' mental health. This research aimed to further explore how and when sleep loss and fatigue impact pilot performance in the cockpit. This was addressed in Study 3 and Study 4.

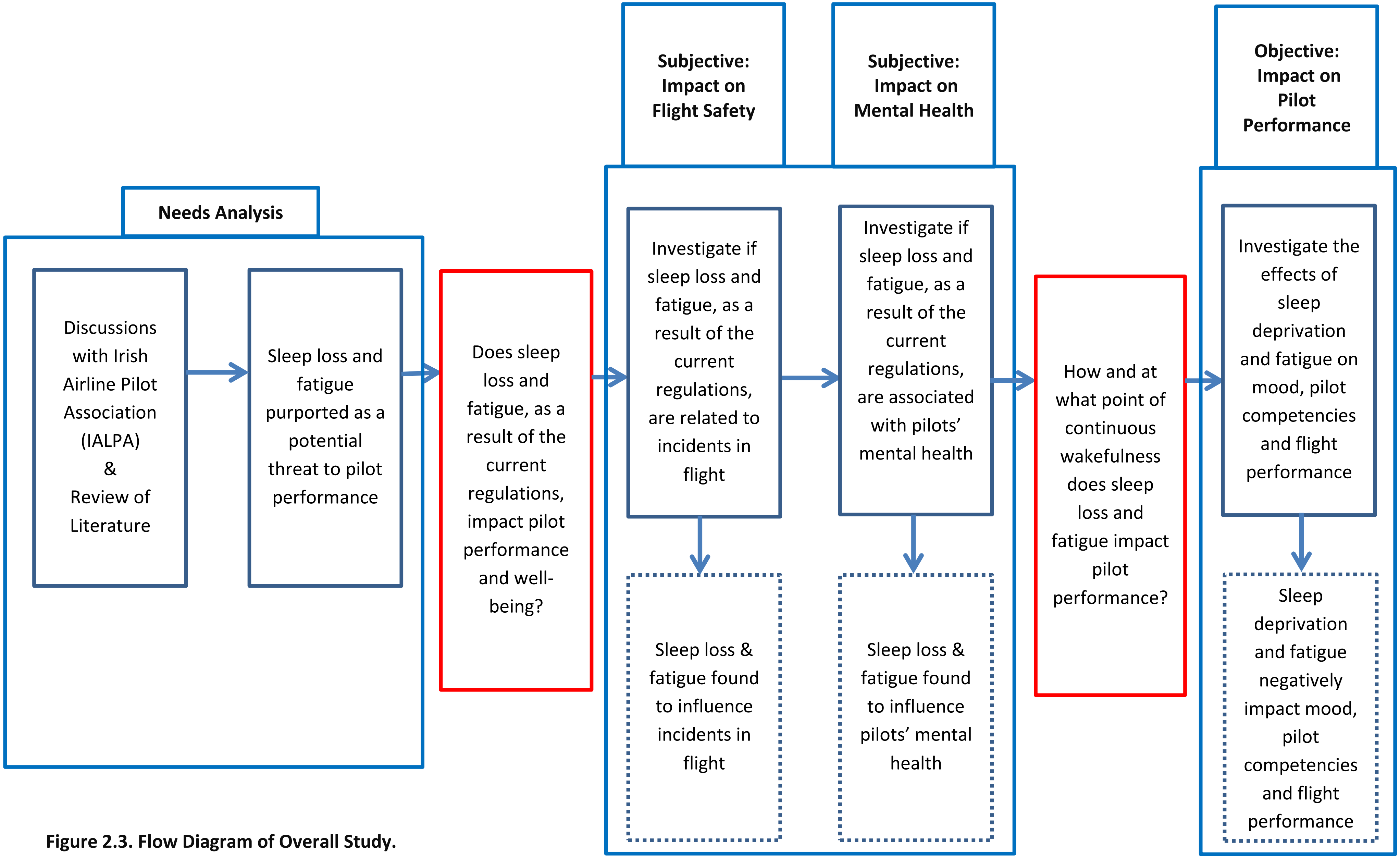

Figure 2.3. Flow Diagram of Overall Study.

Chapter 3

Study 1

3.1 Overview of Study 1

An extensive review of the literature and reports from Moebus Aviation (2008) and the ECA (2012) suggest long working hours, sleep disturbance and fatigue are common occurrences among pilots operating under European regulations. Findings from surveys among some European pilot associations (i.e., SWALPA, DALPA and NRK) indicated that sleep disruption and fatigue is a problematic and prevalent issue. However, no such research has ever been conducted within an Irish context. Informal discussions with airline pilots and members of the Irish Airline Pilots Association (IALPA) have proposed sleep disturbance and fatigue to be widespread among commercial pilots. Furthermore, Ireland is proposed to have in excess of 3,000 commercial airline pilots and is home to Europe's largest low cost airline. For example, in 2016, Dublin airport alone, which operates 24 hours a day, 364 days a year, handled 27.9 million passengers, averaging 541 flights every day (Dublin Airport, 2017). This equates to a pilot taking off or landing in Dublin airport every 2 minutes. It is vital any potential negative influencing factors (i.e., sleepy or fatigued pilots) are addressed and eliminated to ensure a continued safe and successful operation.

Loss of sleep and fatigue could prove highly detrimental to operators' performance, particularly those working round-the-clock operations, such as commercial airline pilots. The impact of sleep loss and fatigue and its negative and sometimes ruinous effects are particularly evident within the aviation industry as demonstrated by previous catastrophic events (e.g., 2004 Corporate Airlines Flight 5966). This initial non-experimental study addressed Primary Objective 1 and Secondary Objective 1. Firstly, it investigated the relationship between pilots' typical duty hours and incidents in flight and examined the potential interplaying role of sleep disturbance and fatigue between these two variables. This question is specifically addressed in 'Study 1'. Furthermore, this study also explored the attitudes and experiences of commercial airline pilots to sleep disturbance and fatigue working under the current Flight Time Limitation regulations. The latter was addressed in the 'Summary of Study 1'.

By addressing these key research objectives, this study aids in providing a more in-depth understanding of the association between potential interplaying factors in the work hours/incidents relationship and as such provides a clearer basis for further investigation and analysis to this complex relationship. Furthermore, it also aids in highlighting the prevalence and magnitude of sleep disturbance and fatigue, and some of their associated consequences, among commercial pilots within Irish cockpits.

3.2 Study 1 – Duty Hours and Incidents in Flight Among Commercial Airline Pilots

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Statement of Contribution: Dr. Johann Issartel and Dr. Giles Warrington were jointly involved in the supervision of this study. Dr. Richard Fletcher was involved in the statistical analysis of this study.

3.2.1 Abstract

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. 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. The fit indices indicated this to be a good fit model ($\chi2 = 11.066$, $df = 5$, $p = 0.05$; 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 ($r = 0.43$, $p < 0.001$). 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

3.2.2 Introduction

A majority of accidents or adverse events within the transport industry have been attributed to human rather than technical errors (Wagstaff & Sigstad, 2011). Several extensive studies have been published indicating that long working hours (more than 50 hours) are associated with an increased risk of incidents and accidents (Caruso, 2006; Dembe et al., 2005; Hanecke et al., 1998). Similar findings have been demonstrated within other sectors of the transport industry, specifically the maritime (Akhtar & Utne, 2014), railway (Dorrian, Baulk, & Dawson, 2011) and road domains (Dept. of Transportation, 2000; Hamblin, 1987). 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 (Caldwell, 2012) and the 1997 Korean Airline Flight 801 incident (NTSB, 1997). 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 (1985) 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 3.1). Dembe et al., (2005) investigated the impact of overtime and long work hours (more than 8 hours per day) on occupational injuries and illnesses employing Schuster and Rhodes' (1985) 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 (Dembe et al., 2005). However, their findings also coincide with alternative hypotheses and therefore cannot be certain of the existence of a causal connection.

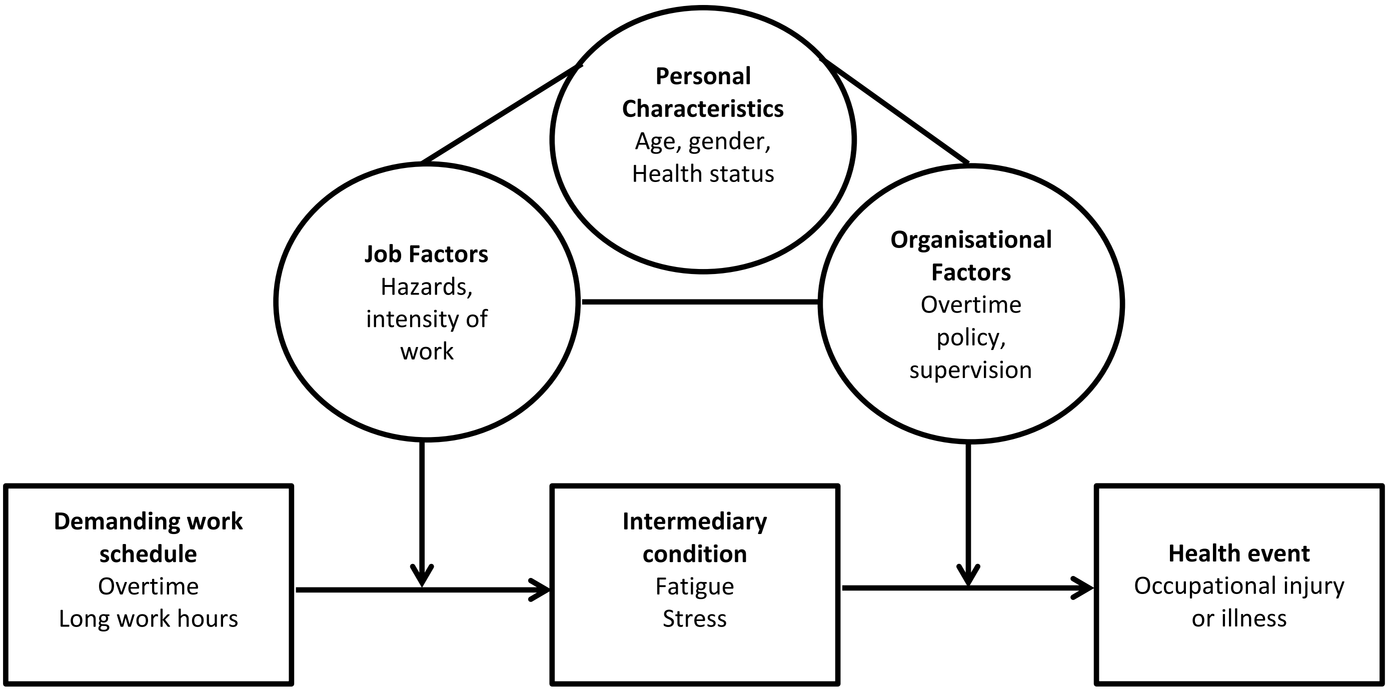

Figure 3.1. Conceptual model of the relationship between demanding work schedules and occupational injuries and illnesses (adapted from Schuster and Rhodes (1985)).

Taking into consideration Schuster and Rhodes' (1985) 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 to result in sleep loss and contribute to fatigue (Howard et al., 2002); (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 (van Dongen et al., 2003); (c) fatigue manifests itself in various ways such as by lapses in attention (Boksem, Meijman, & Lorist, 2005); (d) momentary lapses in attention, regardless of how brief they are, can cause impairments in performance (Horne, Reyner, & Barrett, 2003; Wright & McGowan, 2001); (e) according to Reason's (1990) Accident Causation Model, an accident often arises due to multiple independent events or errors which in turn lead to an accident. Table 3.1 contains an overview of the published literature highlighting the relationship between each of these variables.

Table 3.1. Overview of previously published findings highlighting the relationships between each pair of variables.

Variable 1	Variable 2	Published Research
Duty Hours	Sleep Disturbance	Harrington, 2001; Howard et al., 2002; Ribet & Derriennic, 1999
Duty Hours	Fatigue	Goode, 2003; Hayashi et al., 1996; Rosa, 1995
Sleep Disturbance	Fatigue	Dawson & McCulloch, 2005; Dorrian, Baulk, & Dawson, 2011; Waterhouse, Reilly & Edwards, 2004; Wesensten et al., 2004
Sleep Disturbance	Lapses in Attention	Åkerstedt et al., 2002; Drummond et al., 2001
Fatigue	Lapses in Attention	Boksem, Meijman & Lorist, 2005; Brown, 1994; Rosekind et al., 1999
Fatigue	Error	Campagne, Pebayle, & Muzet, 2004; Gander et al., 2011; Lal & Craig, 2002; Williamson et al., 2011
Fatigue	Incident	Akhtar & Utne, 2014; Dingus et al., 2006; Philip et al., 2001
Lapses in Attention	Error	Åkerstedt et al., 2002; Brown, 1994; Dinhes & Powell, 1985; Edkins & Pollock, 1997
Lapses in Attention	Incident	Åkerstedt et al., 2002; Edkins & Pollock, 1997
Error	Incident	Senders & Moray, 1991; Reason, 1990

Within the aviation industry, there is great concern that pilot schedules can lead to fatigue and increase the likelihood of flight incidents and accidents (Goode, 2003). 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' (ICAO, 2009, 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.

3.2.3 Methods

3.2.3.1. 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) (Appendix A).

3.2.3.2. 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 (2010), the Danish Airline Pilots' Association (2011) and the Swedish Airline Pilots' Association (2011)) 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 (Appendix B) contains time-bound questions (i.e., ‘within the last 3 years’). Note: at the time of survey distribution, current flight time limitations (FTL’s) 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) (2012) for more information pertaining to the rules on Flight and Duty Time Limitations and rest requirements for commercial air transport with aeroplanes.)

3.2.3.3. Path analysis and structural equation modelling (SEM)

This study employed path analysis to test this model (outlined in Figure 3.2) using AMOS 21. Various fit indices were employed to determine how well the proposed model fits the sample data. Initially, $\chi 2$ statistics were used to determine the measure of fit between the sample covariance and fitted covariance matrices (Byrne, 1998). A statistically insignificant value of $\chi 2$ 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 fit (Schumacker & Lomax, 1996). Additionally, the Root Mean Square of Approximation (RMSEA) is another fit index which considers the error of approximation in the population (Byrne, 1998). 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 (MacCallum, Browne, & Sugawara, 1996).

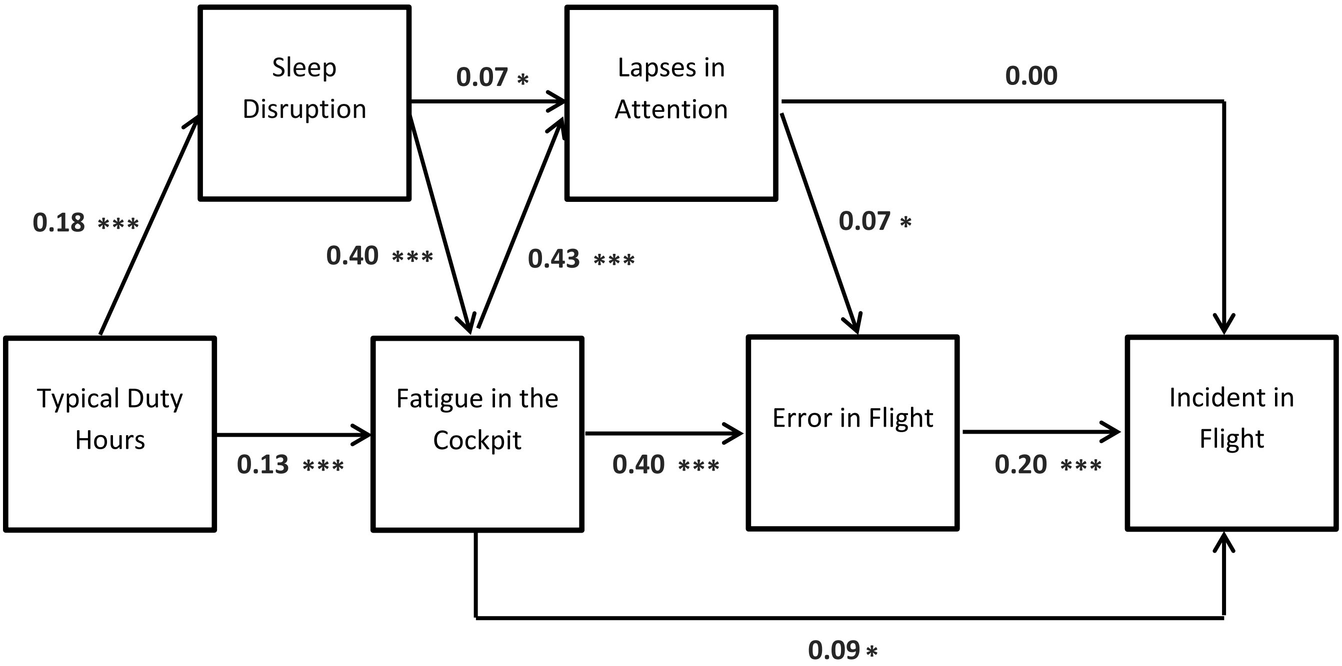

Figure 3.2. Path diagram of proposed model with relationships.

Note: Standardised estimate values are reported. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

3.2.3.4. 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 'optout' 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.

3.2.4 Results

3.2.4.1. 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.

3.2.4.2. Demographic data

In the present sample, 94.9% (*n* = 905) were male while 5.1% (*n* = 49) were female (Table 3.2). 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) 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. These commercial airline pilot demographics replicate those of Reader, Parand & Kirwan (2016) who, to date, have conducted the largest safety culture survey of pilots in Europe investigating the perceptions of safety culture among 7,239 commercial airline pilots across Europe.

Table 3.2. Descriptive and Demographic Data.

Gender:	Male = 94.9% (n = 905) Female = 5.1% (n = 49)
Age:	≤25 yrs = 12.0% (n = 115) 26 – 35 yrs = 42.0% (n = 401) 36 – 45 yrs = 29.0% (n = 277) 46 – 55 yrs = 13.7% (n = 131) 56 – 65 yrs = 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.

3.2.4.3. Path analysis findings

The path analysis findings are pictorially represented in Figure 3.2. 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 ($\chi2 = 11.066$, $df = 5$, $p = 0.050$). 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 same taking into account the sample size (Hooper, Coughlan, & Mullen, 2008). The RMSEA was 0.036, indicative of good fit

(Table 3.3). Therefore, this value implies that the proposed model fits the population's covariance matrix (Byrne, 1998).

Table 3.3. Revised Modification Indices.

Revised modification index	Value
Comparative Fit Index (CFI)	.983
Normative Fit Index (NFI)	.973
Tucker-Lewis Index (TLI)	.956
Root Mean Square of Approximation (RMSEA)	.038

3.2.4.4. 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.

3.2.5 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., (2005) the risk of an accident exponentially increases with time on shift. It was found that relative to 8 hour shifts, there is a 13% increased risk of an accident on 10 hour shifts while 12 hour shifts are associated with a 27% increased risk of an accident. Additionally, Goode (2003) 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 (2003) 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 (Harrington, 2001; Howard et al., 2002). In a study investigating sleeping patterns in the general population, Ribet and Derriennic (1999) 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 hours) 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 (2003) found that as duty hours increase, there is a relatively constant increase in fatigue. However, according to Siegrist (1996) and van der Hulst and Geurts (2001), 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) (1990), the Exxon Valdez accident in 1989 occurred as a result of fatigue due to reduced sleep and extended work hours. Neville et al., (1994) 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. Åkerstedt et al.,

(2002) 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 (Sirois et al., 2009). 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 (2012), 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 (Williamson et al., 2011). According to Akhtar and Utne (2014), 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) (Lauber & Kayten, 1988; Mitler, Dinges, & Dement, 2012). However, a detailed understanding of the relationship between increased fatigue and the risk of accidents has yet to be established (Dawson & McCulloch, 2005). 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 (Murray & Wojciulik, 2004). Landrigan et al., (2004) examined medical interns on call and found that reducing the total work week from 80 to 60 hours per week with a maximum shift of 16 hours (as opposed to 24–36 hours) 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, (1985) 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., (1989) and Sinclair and Tetrick (2004), 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 (1998), 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 (Caldwell, 2012; Gander et al., 2011), none have demonstrated a complete model. Findings from field study research within the medical and aviation industries, by Barger et al., (2006) and Goode (2003), 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.

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 (Sallis & Saelens, 2000). Furthermore, this study did not control for variability of pilot scheduling at the time of survey completion. Moreover, the present study did not employ a validated measure of sleep disturbance or fatigue. Various measures do exist and should be considered for future research such as the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989) and the Multidimensional Fatigue Inventory (MFI) (Smets et al., 1995).

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 (Åkerstedt, 1990; Schuster & Rhodes, 1985) and as such should be included in further investigations.

3.2.6 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.

Acknowledgements

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Disclosure statement

No potential conflict of interest was reported by the authors.

3.3 Summary of Study 1

From Study 1 it was concluded that the proposed work hours/incident model was a strong model fit with those who spend longer hours on duty in a typical week being ultimately more likely to have more incidents in flight with sleep disruption and fatigue found to be key factors in this relationship. This model aids in providing a clearer basis for further investigation in to the work hours/incident debate. Furthermore, this research highlighted the impact and influence of sleep disruption and fatigue and their threat to safety thus encouraging further investigation in to these variables.

Various other key descriptive findings emerged from this non-experimental study which addressed Secondary Objective 1 [to investigate the attitudes and experiences of commercial airline pilots to sleep disturbance and fatigue working under the current Flight Time Limitation regulations] but were not directly referred to in Study 1. These will be briefly discussed now.

A 25-minute, 30-item online survey was developed (discussed in greater detail in Study 1 and Study 2) which addressed the following topics: Demographics, Captain's Discretion, Personal Health, Overall Attitudes and Opinions about Regulations and Associated Bodies, Experiences of Sleep and Fatigue, Errors and Incidents, and Attitudes toward and Experiences of Duty Periods. Two thousand, one hundred and eighty-six Irish-registered commercial airline pilots were emailed a direct link to the survey which they completed online. Each pilot was sent a unique link which could be used only once in order to prevent replication. Nine hundred and fifty four Irish-registered commercial airline pilots successfully completed the survey representing a 43.64% response rate. This equates to just under one-third (31.80%) of this overall pilot cohort. Please see Table 3.2 for the descriptive and demographic data.

Of those surveyed, 23.67% (a majority) reported spending 36 – 40 hours on duty in a typical week while 18.35% reported spending more than 45 hours on duty in a typical week (See Figure 3.3). Overall, 81.65% of pilots indicated that they typically spend less than or equal to 45 hours on duty in a typical week. From the other European pilot surveys conducted, 58% of Danish pilots and 61.2% of Norwegian pilots indicated that they spend 45 – 50 hours on duty in a typical week while 56% of Swedish pilots indicated that they rarely spend more than 45 hours on duty in a typical week. It appears pilots flying for Irish-registered airline typically report spending less hours on duty per week relative to their European counterparts. While each European state must abide by the FTL regulations set out by EASA, it is up to each country individually how they manage pilots' flight and duty hours potentially explaining the differences observed here.

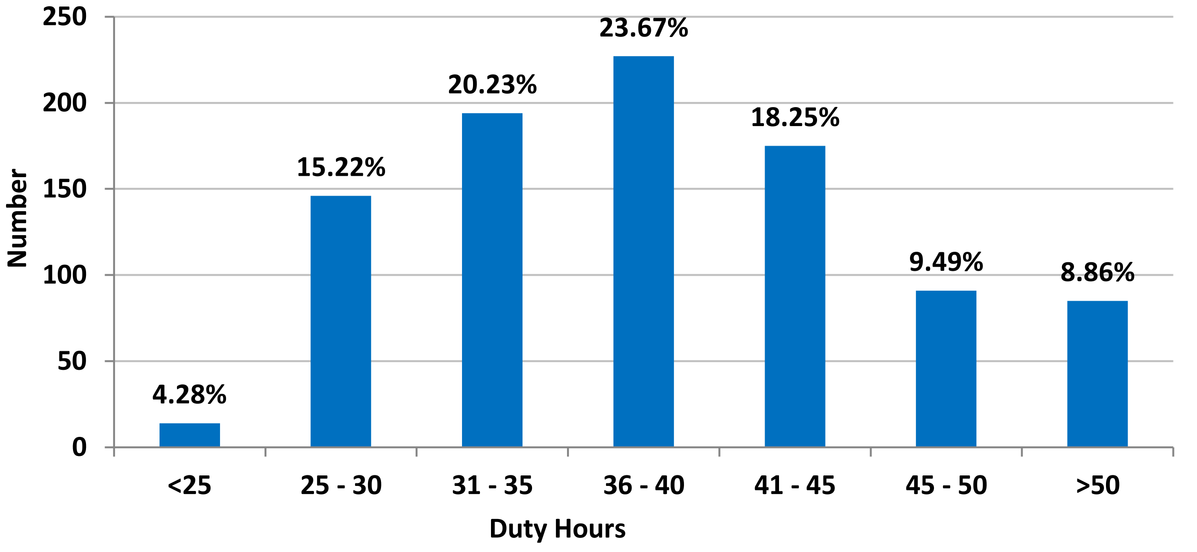

Figure 3.3 Number of hours pilots reporting spending on duty in a typical week.

As can be seen in Table 3.4, 30.68% of those who reported operating duties of <u><</u>8 hours indicated they performed these <u>></u>8 times in a typical calendar month while 31.56% of those who reported operating duties of >8 but <u><</u>10 hours also reported performing these <u>></u>8 times in a typical calendar month. One third (33.69%) of those who reported operating duties of >10 but <u><</u>12 hours indicated they performed these 2 – 3 times in a typical calendar month while 29.41% who reported operating duties of >12 but <u><</u>14 hours indicated the performed these once in a typical calendar month.

Table 3.4. Breakdown of amount and occurrence of hours typically spent on duty.

	1	**2 – 3**	**4 – 5**	**6 – 7**	**≥8**	**Never**
≤8 hrs	28 (3.28%)	166 (19.44%)	208 (24.36%)	178 (20.84%)	262 (30.68%)	12 (1.41%)
>8 but ≤10 hrs	17 (1.88%)	133 (14.73%)	242 (26.80%)	219 (24.25%)	285 (31.56%)	7 (0.78%)
>10 but ≤12 hrs	109 (12.84%)	286 (33.69%)	219 (25.80%)	98 (11.54%)	111 (13.07%)	26 (3.06%)
>12 but ≤14 hrs	155 (29.41%)	83 (15.75%)	18 (3.42%)	10 (1.90%)	11 (2.08%)	250 (47.44%)
≥14 hrs	31 (6.94%)	6 (1.34%)	1 (0.22%)	1 (0.22%)	3 (0.67%)	405 (90.60%)

Findings from this in-depth survey suggest that there is a very serious issue of sleep disturbance among Irish-registered commercial airline pilots with 33.06% (yes, a few times/month), 34.52% (yes, several times/month) and 22.73% (yes, several times/week) of those surveyed reporting that their work as a commercial pilot negatively influences their ability to adopt normal sleeping patterns that allow proper rest on a regular bases (see Figure 3.4). Of those who reported their work as a commercial pilot negatively influenced their ability to adopt normal sleeping patterns that allow proper rest on a regular basis; 98.05% reported often feeling too tired/fatigue to be on active duty in the cockpit; 94.85% reported often experiencing micro-sleeps in the cockpit; while 97.91% reported been involved in an incident/s where they felt that their fatigue or that of their pilot colleague was a contributory factor. The SWALPA survey recorded that participants felt the current regulations contained in the EU-OPS Subpart Q were a high (44%) or very high (38%) safety risk as they contribute to a lack of proper rest and sleep.

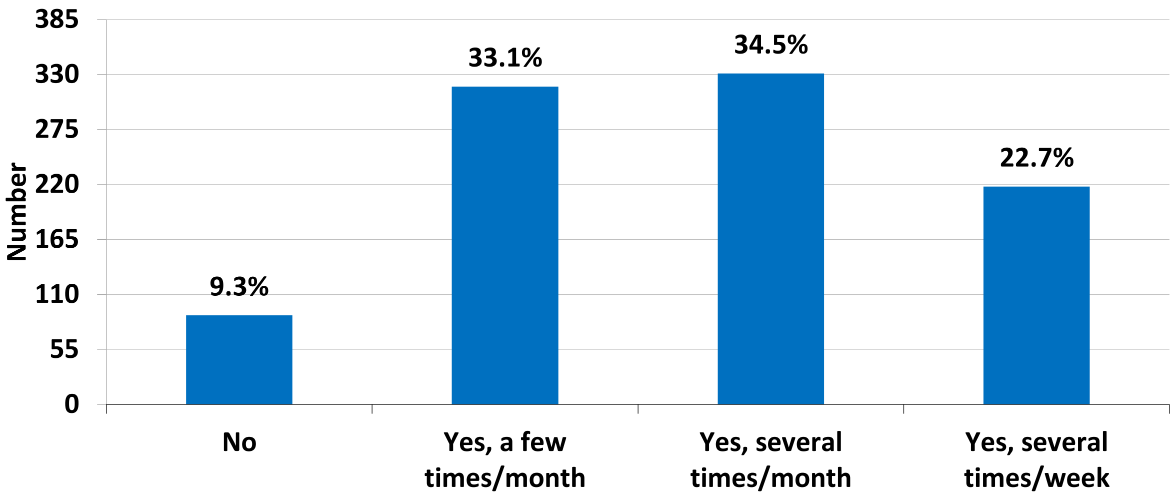

Figure 3.4 Number of pilots reporting inability to adopt normal sleeping patterns that allow proper rest on regular bases as a result of work as a commercial pilot.

85.72% (13.56% + 50.68% + 21.48%) of those surveyed reported that they have, at one stage or another, felt so tired or fatigued they felt they should not be on active duty in the cockpit with 1 in every 5 (21.48%) reporting that they often feel this way (see Figure 3.5). In comparing these figures with the other European studies, 89% (9% + 57% + 23%) of Swedish pilots, 94% (8% + 60% + 26%) of Danish pilots and 82.9% (5.2% + 65.2% + 17.7%) of Norwegian pilots reported, at one stage or another, feeling so tired or fatigued that they felt they should not be on active duty in the cockpit. Swedish and Danish pilots appear to report higher incidences of feelings of fatigue in the cockpit relative to pilots flying for Irish airlines.

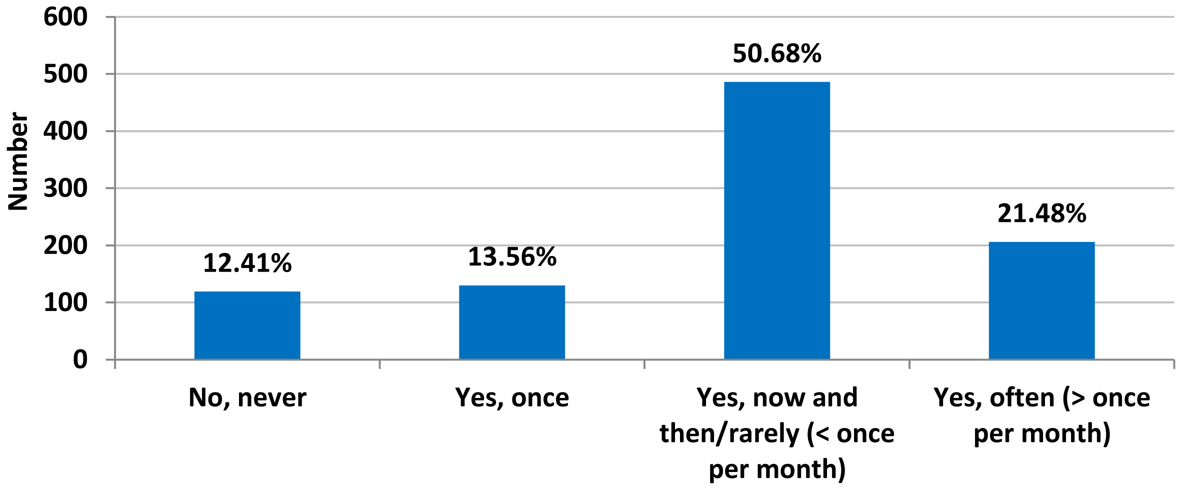

Figure 3.5 Number of pilots reporting having felt so tired/fatigued, they felt they should not be on active duty in the cockpit.

79.1% of those surveyed indicated that they have, at one stage or another, experienced a micro-sleep or fell asleep in the cockpit, without prior agreement with the other pilot (Figure 3.6). Of those that reported having previously felt so tired or fatigued they felt they should not be on active duty in the cockpit; 91.43% have experienced a micro-sleep or have fallen asleep in the cockpit, without prior agreement with the other pilot. In comparison with the other European studies, 54% (16% + 32% +6%) of Swedish pilots, 50% (15% + 31% + 4%) of Danish pilots and 53.4% (10.1% + 41% + 2.3%) or Norwegian pilots reported having, at some stage or another, experienced a micro-sleep or fallen asleep while on active duty in the cockpit without prior agreement with the other pilot. As can be identified from these results, pilots flying for Irish-registered airlines reported considerably higher values in each instance relative to their European counterparts.

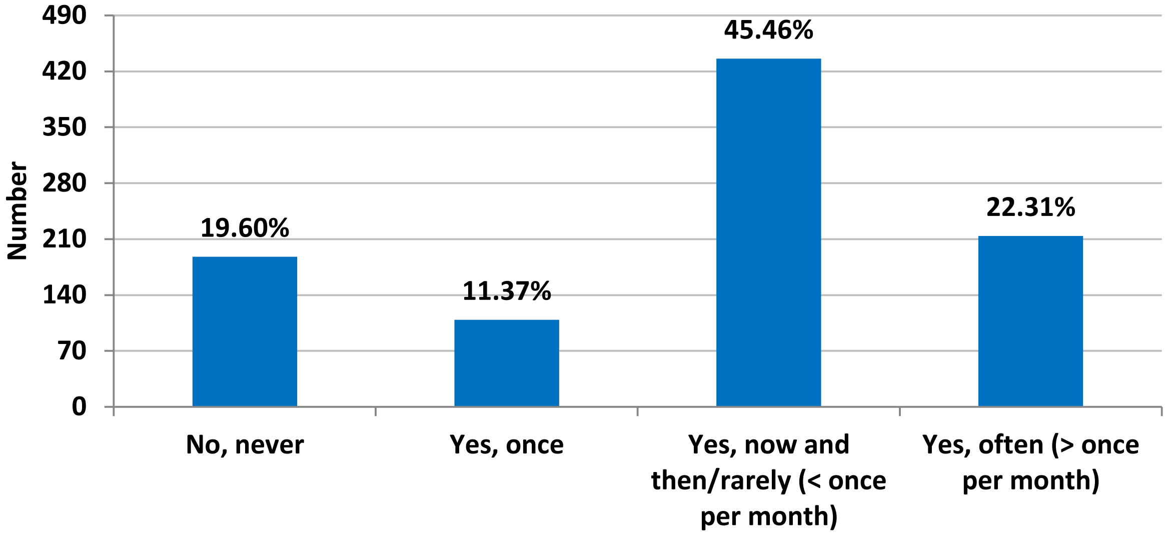

Figure 3.6 Number of pilots reporting having experiencing a micro-sleep event, or fallen asleep while actively on duty in the cockpit, without prior agreement with the other pilot.

468 (49.05%) pilots who completed the survey indicated that they had made what they consider an error(s)[2] affecting flight safety which they attribute solely to fatigue while on active duty in the cockpit. Of the 468 who answered 'yes' – 401 provided details of the event. The main errors reported by pilots were – missed radio calls, missed checks, reduced situational awareness, forgetting tasks, sloppy flying, miscalculations, slowed responses/reactions and missed ATC instructions. Furthermore, 1 in every 10 (10.01%) participants reported that had been involved in an incident(s)[3] where they felt that their fatigue or that of their pilot colleague was a contributory factor. In comparison,, 71% of SWALPA, 90% of DALPA and 79% of NRK pilots indicated that they had made errors affecting flight safety which they attribute solely to fatigue while on active duty in the cockpit. No further information or description was provided of the errors.

81.86% of those surveyed felt the current regulations contained in EU-OPS Subpart Q provided flight and cabin crew with a low level (52.97%), a very low level (25.03%) or no protection at all (3.86%) against threats posed by fatigue. These survey findings found very high incidences of disturbed sleep, feelings of fatigue and micro-sleep events in the cockpit among Irish-

[2] *Error: An action or inaction by the flight crew that leads to deviations from organisational or flight intentions or expectations (EASA, 2009).*

[3] *Incident: An occurrence…associated with the operation of an aircraft which affects or could affect the safety of operation (ICAO Annex 13).*

registered airline pilots. Relative to other European surveys, the pilots surveyed here, who fly for Irish-registered airlines, were found to spend less hours on duty in a typical week, reported less instances of feeling too tired/fatigued to be on active duty in the cockpit and reported making less errors affecting flight safety. However, Irish-registered commercial airline pilots reported considerably higher instances of micro-sleeps or falling asleep while on active duty in the cockpit. These findings suggest that sleep disturbance and fatigue is a very serious and prevalent issue in Irish cockpits which has the potential to negatively influence flight safety.

3.4 Link Section from Chapter 3 to Chapter 4

From Study 1, it was concluded that there was a strong relationship between duty hours and incidents in flight with those who spend more hours on duty being more likely to experience an incident in flight. Furthermore, sleep disturbance and feelings of fatigue were observed to play a key role in the pathway between these variables. Much of the previous scientific literature pertaining to sleep loss and fatigue has tended to focus on its impact on workers performance (e.g., Russo et al., 2005). However, as well as impacting performance, sleep plays an integral role in mental health and well-being.

The Germanwings incident in March 2015 in which depressed pilot, Andreas Lubitz, deliberately crashed the aircraft he was flying killing 150 people on board raised interest in to the mental health and well-being of commercial airline pilots. According to Butcher (2002), mental health issues among pilots have been identified, but the extent, origins, or degree of these problems among active airline pilots is currently unknown because no decisive epidemiological studies on rates of mental disorders have been conducted for this population. The survey data collected in Study 1 contained self-reported information regarding pilots' perceptions of their mental health.

The association between mental health and well-being, and work hours is of growing interest and concern with an increasing body of evidence suggesting longer work hours adversely affect mental health. Sleep disruption, feelings of fatigue and manifestations of fatigue (e.g., microsleeps) as a result of long working hours have been found to be associated with depression and anxiety (Sirois et al., 2009). Sleep disturbance and fatigue have substantial short-term and long-term consequences not only on pilot safety, but on pilot health also (Steptoe & Bostock, 2011) which in turn can impact flight safety.

Emotional and mental health factors have been found to negatively influence flight performance (Butcher, 2002). Therefore, utilising the survey data collected during Study 1, Study 2 explored self-reported depression and anxiety among Irish-registered commercial airline pilots and the influence of working hours and sleep factors on these. This study aided in increasing awareness and understanding of the insidious and prevalent threats of sleep loss and fatigue on pilot mental health and well-being.

Chapter 4

Study 2

4.1 Overview of Study 2

Following on from Study 1 in which a strong relationship between duty hours, sleep disturbance and incidents in flight was identified, this research aimed to further explore the influence of sleep and fatigue on pilot mental health and well-being among pilots who fly for Irish-registered airlines. Existing evidence raises concern about the negative impact of long work hours on operators' health and well-being (Harrington, 2001), thus warranting further investigation based on the findings of this research so far regarding long working hours. As previously mentioned Ireland is proposed to have in excess of 3,000 commercial airline pilots and is home to Europe's largest low cost airline. The survey findings collected in Study 1 provide an excellent opportunity in which to further explore the relationship between duty hours and self-reported mental health.

Regularly experiencing insufficient sleep (less than seven hours) has been linked with an increased risk of anxiety and depression (Walker & Stickgold, 2006), with regular sleep disturbance, as a result of work as a commercial pilot, already identified as a common occurrence among this cohort in Study 1. Baglioni et al., (2011) concluded that those with poor sleep and no depression at baseline had a two-fold risk of developing depression when re-evaluated 1 year or more later, relative to those with no sleep difficulties. According to the literature, some factors associated with long work hours and depression or anxiety include sleep disruptions, feelings of fatigue, and manifestations of fatigue (e.g., microsleeps) (Sirois, Trutschel, Edwards, Sommer, & Golz, 2009).

Research examining length of work hours, sleep disturbance and workers' mental health is sparse (Spurgeon et al., 1997). This non-experimental cross-sectional study addressed Primary Objective 2. It investigated differences in self-reported depression or anxiety among commercial airline pilots and further investigated the extent to which these differences could be explained, initially by individual demographic characteristics (e.g., age, position, employment), and subsequently by experiences of fatigue in the cockpit, experiences of microsleeps in the cockpit, and sleep disturbance due to work schedule.

By addressing these questions, this research aids in highlighting the universal impact of sleep disturbance and fatigue. Furthermore, this research raises awareness to self-reported ratings of depression and anxiety among commercial airline pilots and the potential influence of work hours, sleep disturbance and feelings of fatigue.

4.2 Study 2 – Flying Into Depression – Pilot's Sleep and Fatigue Experiences Can Explain Differences in Perceived Depression and Anxiety Associated With Duty Hours

Anna Donnla O'Hagan, Johann Issartel, Alan Nevill & Giles, Warrington

Workplace Health & Safety. DOI: 10.1177/2165079916659506

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Statement of Contribution: Dr. Johann Issartel and Dr. Giles Warrington were jointly involved in the supervision of this study. Dr. Alan Nevill was involved in the statistical analysis of the study.

4.2.1 Abstract

A growing body of evidence suggests long work hours adversely affect mental health across a variety of domains. Mental health issues have been found to negatively affect work performance. This finding was highlighted in the aviation industry by the 2015 Germanwings incident in which 150 people died. Further investigation into work hours and their associated factors (e.g., demographic characteristics and experiences of sleep and fatigue in the cockpit) contributing to mental health issues among pilots is warranted. A cross-sectional survey investigating attitudes and experiences of fatigue was developed and distributed to commercial airline pilots. Results found pilots who reported typically spending longer hours on duty per week were twice as likely to report feeling depressed or anxious. Pilots' experiences of job-related sleep disturbance and fatigue may explain why pilots who typically spend long hours on duty each week are more likely to report feeling depressed or anxious.

Keywords: depression in pilots; duty hours; sleep disturbance; fatigue; binary logistic regression

4.2.2 Introduction

The association between mental health and well-being, and work hours is of growing interest and concern with an increasing body of evidence suggesting longer work hours adversely affect mental health across a variety of occupations (Dembe, Erickson, Delbos, & Banks, 2005). Various studies have identified an association between overtime and extended work schedules with increased risk of worker fatigue (Åkerstedt, Fredlund, Gillberg, & Jansson, 2002; Park, Kim, Chung, & Hisanaga, 2001), stress (Maruyama & Morimoto, 1996), and depression (Proctor, White, Robins, Echeverria, & Rocskay, 1996; Shields, 1999). Several meta-analyses such as those by Sparks, Cooper, Fried, and Shirom (1997) and Spurgeon, Harrington, and Cooper (1997) summarized these research findings. The literature suggests that longer work hours are associated with adverse effects on workers' mental health. Further investigation into work hours and concomitant factors contributing to workers' mental health is warranted.

Mental health issues, which can be detrimental to quality of life, can also have a negative influence on work performance (Butcher, 2002). Depending on occupation, mental health issues can have serious widespread consequences. The mental health of commercial airline pilots has been found to influence flight performance (Butcher, 2002). Within the aviation industry, the potential incidence of mental health issues among pilots is a serious concern due to operation of multi-million euro airframes and the lives of 500 or more passengers. This loss of life and equipment was recently highlighted on March 24, 2015, when co-pilot Andreas Lubitz, having locked the captain out of the cockpit, crashed Germanwings Flight 9525 into the French Alps killing 150 passengers and crew. Further investigation found that Lubitz had a history of severe depression. This fatal incident is not isolated. On October 31, 1999, 30 minutes after take-off from New York City, an EgyptAir Boeing 767 experienced a rapid descent killing 217 individuals. Inconclusive evidence suggested that the crash was deliberately caused by the relief first officer (Aviation Safety Network, 1999). Furthermore, on December 19, 1997, Silk Air Flight 185 crashed following a rapid descent from cruising altitude on route from Jakarta, Indonesia to Singapore killing 104 on board. In the subsequent incident report, it was suggested that the captain was suffering from "multi-work related difficulties" (Aviation Safety Network, 1997). According to Butcher (2002), mental health issues among pilots have been identified, but the extent, origins, or degree of these problems among active airline pilots is currently unknown because no decisive epidemiological studies on rates of mental disorders have been conducted for this group.

One factor proposed to have a strong impact on mental health, specifically depression, is long work hours (i.e., more than 8 hours; Proctor et al., 1996). Pilots flying for European-based air carriers can fly up to 13 hours per duty day (European Union Air Operations [EU-OPS]-Subpart Q[4]). Commercial pilots assigned to U.S.-based flights can fly up to 9 hours per duty day based on a two-pilot crew (Federal Aviation Administration [FAA]-14 CFR Part 117[5]). Pilots flying for U.K.-based carriers are permitted to fly up to 13 hours per duty day (Civil Aviation Authority [CAA-UK]-CAP 371[6]) while commercial pilots operating Chinese-based flights can spend up to 14 hours on duty per day, although flight time cannot exceed 10 hours (China Civil Aviation Regulations [CCAR]-Section 135[7]). These flight time limitations implemented by various aviation regulation authorities suggest further evaluation is needed worldwide regarding pilot work hours.

A number of previous studies have investigated the relationship between work hours and health (Proctor et al., 1996; Sparks et al., 1997; van der Hulst, 2003). The mental health of shift workers has also received some attention (Harrington, 2001; Kim et al., 2002). In contrast, research examining quantity of work hours and workers' mental health is much sparser (Spurgeon et al., 1997). Regardless, existing evidence causes concern about the negative impact of longer work hours on the health and well-being of workers (Harrington, 2001; Spurgeon et al., 1997; van der Hulst, 2003). In a meta-analysis based on 21 studies, Sparks and colleagues (1997) found a small but significant positive correlation between longer work hours and poorer psychological health. Furthermore, qualitative analysis of an additional 12 studies supported these findings (Sparks et al., 1997). Using the results from the Third European Working Conditions Survey, completed by 21,703 workers in face-to face interviews across the 15 European Union member states in 2000, Boisard, Gollac, Valeyre, and Cartron (2003) found that of those who worked 30 to 35 hours per week, 27% and 19% reported experiencing stress and overall fatigue, respectively, due to work. Whereas, of those employees who worked 45 hours or more per week, 39% and 33% reported experiencing stress and overall fatigue, respectively, due to work. The researchers concluded that the frequency of reported mental health issues was significantly correlated with work time.

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[4] *EU-OPS – Subpart Q – a legally, binding minimum set of flight time limitation safety rules aimed at preventing pilot fatigue across Europe.*

[5] *FAA – 14 CRF Part 117 – flight and duty-time limitations and rest requirements for flightcrew members in the United States.*

[6] *CAA-UK – CAP 371 – regulations for flight crews and cabin staff designed to prevent the onset of fatigue for non-European Aviation Safety Agency flight time limitation operations.*

[7] *CCAR – Section 135 – a set of operating requirements to attain and maintain a level of safety, in accordance with the People's Republic of China civil aviation law.*

Although long work hours appear to be associated with mental health issues, the potential influence of confounding factors (i.e., demographic variables, job demands, work characteristics, and personality) may also play a role in this relationship (Spurgeon et al., 1997; van der Hulst, 2003). Previous research has used the number of hours worked as an indicator of task demands (van der Hulst, 2003). However, such an approach cannot clearly separate the effects of job demands and long work hours. Basic correlations between work hours and health effects provide limited information. According to van der Hulst (2003), failure to control for covariates may contribute to inconclusive findings in investigations of work hours and mental health.

According to the literature, some factors associated with long work hours and depression or anxiety include sleep disruptions, feelings of fatigue, and manifestations of fatigue (e.g., microsleeps; Samel, Wegmann, & Vejvoda, 1997; Sirois, Trutschel, Edwards, Sommer, & Golz, 2009). Until now, no published studies have investigated to what extent self-reported depression or anxiety due to work hours might be explained by sleep disruption and fatigue adjusted for individual pilots' demographic characteristics. The purpose of the current study was therefore to investigate the differences in self-reported depression or anxiety among European-registered commercial airline pilots, and then to further investigate the extent to which these differences could be explained, initially by individual demographic characteristics (e.g., age, position, employment), and subsequently by their experiences of fatigue in the cockpit, experiences of microsleeps in the cockpit, and sleep disturbance due to work schedule.

4.2.3 Methods

This study analysed data from a cross-sectional survey of European-registered commercial airline pilots conducted between September and November 2012. All participants in the current study flew for airlines all registered to the same European state. A total of 701 commercial airline pilots fully completed the anonymous online survey. Prior to distribution of the survey, ethical approval was granted by Dublin City University Ethical Committee (Appendix A).

4.2.3.1 Sample

A total of 2,186 European-registered commercial airline pilots' email addresses were obtained. Pilots were emailed details outlining the purpose of the study and a link to the online survey. Of the distributed surveys, 701 were fully completed, representing a 32% response rate.

4.2.3.2 Survey Description

The survey was based on three previous unpublished European pilot fatigue surveys conducted by the Norwegian Airline Pilots' Association (2010), the Danish Airline Pilots' Association (2011), and the Swedish Airline Pilots' Association (2011). The 25-minute survey collected data on the following topics: Demographics, Captain's Discretion, Personal Health, Overall Attitudes and Opinions about Regulations and Associated Bodies, Experiences of Sleep and Fatigue, Errors and Incidents, and Attitudes toward and Experiences of Duty Periods.

Following a review of the literature, analysis of other European pilot fatigue surveys and discussions with experienced European-based commercial airline pilots, a 30-item survey was created using the web-survey development, cloud-based product, SurveyMonkey®. Prior to survey distribution, the acceptability of the survey and question ambiguity were determined by two postgraduate researchers, a university researcher, and two commercial airline pilots with combined flying experience of more than 30 years (Williams, 2003). These individuals were also asked to provide opinions on the overall content of each item as a determination of "face validity." The questions were then amended accordingly. The revised survey was sent to four professionals (i.e., two commercial airline captains, one university professor, and one university researcher), who had conducted other European pilot fatigue surveys, to ascertain their opinions on instrument layout and content. This process acted as a measure of "content validity"; after analysis, appropriate alterations were implemented. Following this, 10 pilots who currently fly with European-registered airlines were randomly selected and asked to complete the online survey which gathered data about their opinions on the language used, duration, layout, and overall content. Following this process, final changes were made. The 30-item survey (Appendix B) included time-bound questions. The current flight time regulations at the time of the survey, under the auspices of the EU-OPS Subpart Q, were effective in July 2008. Therefore, all questions in this survey referred to the period from July 2008 to the day on which the survey was completed, unless otherwise stated (e.g., "in the last 12 months") from the time of taking the survey.

4.2.3.3 Outcome Measure

Perceived depression or anxiety was measured by a response to the self-rated depression question "In the past 12 months, have you ever suffered from feelings of being . . . depressed or anxious?" Respondents answered on a 5-point Likert-type scale ranging from *no, never; yes, once; yes, now and then/rarely; yes, often*; or *don't know/no opinion*. These responses to the self-rated depression and anxiety questions were also dichotomised to those reporting not having experienced depression or anxiety in the last 12 months and those reporting having experienced depression or anxiety in the last 12 months by assigning 0 to those reporting either "no" or "don't know/no opinion"; and 1 to those reporting "yes, once," "yes, now and then/rarely," and "yes, often."

4.2.3.4 Statistical Analyses

Pearson's chi-square tests of independence were performed to investigate the association between the number of respondents typically working less than 25 hours on duty, 25 to 30 hours, 31 to 35 hours, 36 to 40 hours, 41 to 45 hours, 46 to 50 hours, and greater than 50 hours per week, and their perceived depression or anxiety. Due to the likely effect of confounding variables (i.e., age, gender, and experiences of sleep disruption and fatigue caused by occupation), binary logistic regression was used to further explore these issues in perceived depression or anxiety. By assigning the dichotomous indicator of "have experienced depression or anxiety" as the response variable, an initial model investigated the unadjusted differences in typical duty hours per week (i.e., less than 25 hours on duty, 25 to 30 hours, 31 to 35 hours, 36 to 40 hours, 41 to 45 hours, 46 to 50 hours, and more than 50 hours per week; Model 1). This model was subsequently adjusted for other demographic factors (i.e., gender, age, position, living situation, contract, and employment) in Model 2, and then finally adjusted by adding sleep and fatigue factors (i.e., experiences of fatigue in the cockpit, experiences of microsleeps in the cockpit, and sleep disturbance due to working schedule) reported as Model 3. (See Appendix C for additional information on the analysis).

4.2.4 Results

A Pearson's chi-square test of independence was used to investigate the association between typical duty periods and self-reported depression or anxiety. Findings showed that as number of hours on duty increased, pilots reported a significant increase in depression or anxiety ($\chi2$ = 14.215; $p < .05$). In response to the Likert-type self-rated depression or anxiety question, the findings suggested that pilots who typically spend 36 to 40 hours on duty per week are more likely to report feeling depressed or anxious relative to any other duty hour periods (Table 4.1). Due to the likely effect of confounding variables, binary logistic regression was used to further explore self-reported depression or anxiety.

Table 4.1. Frequency (%) of Responses to the Likert Self-Rated Depression or Anxiety Question by Typical Hours Spent on Duty per Week.

Number of individual responses to the question: "In the past 12 months, have you ever suffered from feelings of being…depressed or anxious?"			
Typical Duty Hours Per Week	**No, Never (%)**	**Yes (Once, Now & Then/Rarely, Often) (%)**	**Total (%)**
<25 Hours	19 (63.3)	11 (36.7)	30 (100)
25 – 30 Hours	51 (50.0)	51 (50.0)	102 (100)
31 – 35 Hours	73 (51.0)	70 (49.0)	143 (100)
36 – 40 Hours	76 (44.7)	94 (55.3)	170 (100)
41 – 45 Hours	46 (35.4)	84 (64.6)	130 (100)
45 – 50 Hours	26 (37.7)	43 (62.3)	69 (100)
>50 Hours	29 (50.9)	28 (49.1)	57 (100)
Total	320 (45.6)	381 (54.4)	701 (100)

Note. Chi-square χ^2 (df = 6) = 14.215 (*P* = .027)

4.2.4.1 Factors Associated With Duty Hours Adjusted for Demographics

The unadjusted binary logistic regression analysis (see Table 4.2, Model 1) identified that pilots working 41 to 45 hours and 45 to 50 hours had a significantly higher probability of reporting feeling depressed or anxious in the last 12 months (odds ratio [OR] = 3.15, 95% confidence interval [CI] = [1.38, 7.19] and OR = 2.85, 95% CI = [1.17, 6.94]) than those who worked less than 41 hours per week. Those who reported typically spending 36 to 40 hours on duty per week approached significance (OR = 2.13, 95% CI = [0.95, 4.76]) compared with those who reported typically spending less than 25 hours on duty per week (baseline level). The resulting analysis identified a strong effect of gender; females were significantly (2.6 times) more likely to report feeling depressed or anxious (OR = 2.61, 95% CI = [1.12, 6.07]) compared with males (baseline group). Furthermore, those aged 46 to 55 years were also found to be significantly (2 times) more likely to report feeling depressed or anxious (OR = 2.15, 95% CI = [1.02, 4.52]) compared with those participants aged less than 25 years in the baseline group.

4.2.4.2 Factors Associated With Duty Hours, Adjusted for Demographic Characteristics and Experiences in the Cockpit

A third binary logistic regression analysis (Model 3) was completed incorporating experiences of fatigue in the cockpit, experiences of microsleeps in the cockpit and sleep disturbance due to work schedule in addition to those variables included in Model 2. The aim of this analysis was to determine the experiences in the cockpit associated with feelings of depression or anxiety and explain the above demographic differences. When pilots' experiences of fatigue and sleep disruption due to work were incorporated into the binary logistic regression analysis, the differences in perceived depression or anxiety due to typical hours spent on duty disappeared (see Table 4.2, Model 3). The resulting analysis identified the effect of fatigue in the cockpit. As frequency of experiences of fatigue in the cockpit increased, participants reported a progressive increase in the likelihood of reporting feeling depressed or anxious. Those pilots who reported rarely feeling too fatigued to be on active duty in the cockpit were more than twice as likely to report feeling depressed or anxious (OR = 2.31, 95% CI = [1.32, 4.02]). Those who reported often feeling too fatigued to be on active duty in the cockpit were more than 5 times as likely to report feeling depressed or anxious (OR = 5.39, 95% CI = [2.65, 10.96]) compared with those who reported never feeling too fatigued to be on active duty in the cockpit (baseline group). Furthermore, those pilots who reported experiencing sleep disturbance due to work several times per week were more than 3 times more likely to report feeling depressed or anxious (OR = 3.16, 95% CI = [1.56, 6.43]) compared with those pilots who reported never experiencing sleep disturbance due to their occupation. Those who reported often experiencing microsleeps in the cockpit were significantly more likely to report feeling depressed or anxious (OR = 2.41, 95% CI = [1.34, 4.35]) relative to those who reported never experiencing microsleeps in the cockpit (baseline group).

Further analysis revealed that when experiences of fatigue and sleep due to work were incorporated into Model 3, the effects of age (46-55 years) disappeared. No age group reported significantly more feelings of depression or anxiety compared with the less than 25 year old baseline group. However, significant differences in gender remained (OR = 3.57, 95% CI = [1.44, 8.81]) with females being more than 3 times more likely to report feeling depressed or anxious than males.

Table 4.2. Differences in Perceived Depression or Anxiety Due to Duty Hours Alone (Model 1), Adjusted for Individual Demographics (Model 2) and Adjusted for Both Individual Demographics and Sleep Disturbance and Fatigue Experiences (Model 3).

		Model 1 Unadjusted differences	Model 2 Adjusted for individual characteristics	Model 3 Adjusted for individuals and behavioural characteristics
		OR (95% CI)	OR (95% CI)	OR (95% CI)
Duty Hours	<25 Hours	1.00	1.00	1.00
	25 – 30 Hours	1.72 (.74–3.99)	1.69 (.72–3.94)	1.05 (.41–2.67)
	31 – 35 Hours	1.65 (.73–3.73)	1.57 (.69–3.57)	.92 (.37–2.29)
	36 – 40 Hours	2.13 (.95–4.76)	2.04 (.90–4.62)	1.17 (.48–2.88)
	41 – 45 Hours	3.15 (1.38–7.19)	3.04 (1.31–7.06)	1.31 (.51–3.34)
	45 – 50 Hours	2.85 (1.17–6.94)	2.67 (1.08–6.57)	.91 (.33–2.50)
	>50 Hours	1.66 (.67–4.12)	1.52 (.60–3.82)	.74 (.27–2.06)
Gender	Male		1.00	1.00
	Female		2.61 (1.12–6.07)	3.57 (1.44–8.81)
Age Group	<25 Years		1.00	1.00
	26 – 35 Years		1.52 (.89–2.59)	1.34 (.75–2.38)
	36 – 45 Years		1.76 (.92–3.34)	1.56 (.77–3.16)
	46 – 55 Years		2.15 (1.02–4.52)	1.82 (.80–4.10)
	56 – 65 Years		1.47 (.44–4.85)	.94 (.25–3.52)
Position	Captain		1.00	1.00
	First/Second Officer		.91 (.62–1.32)	.91 (.60–1.37)
Employment	Full-Time		1.00	1.00
	Part-Time		.583 (.21–1.57)	.54 (.17–1.65)
Contract	Permanent		1.00	1.00
	Contract		1.36 (.96–1.93)	1.37 (.93–2.01)
Living Situation	Living with a partner		1.00	1.00
	Living alone		1.02 (.66–1.57)	1.03 (.64–1.66)
	Living with parents/friends		1.24 (.72–2.14)	1.15 (.64–2.07)
	Other		.62 (.30–1.28)	.57 (.26–1.24)
Sleep Disturbance	Never			1.00
	A few times per month			1.42 (.75–2.68)
	Several times per month			1.69 (.88–3.25)
	Several times per week			3.16 (1.56–6.43)
Experiences of	Never			1.00

Fatigue in the Cockpit	**Once**			1.48 (.78–2.83)
	Now and Then/Rarely			2.31 (1.32–4.02)
	Often			5.39 (2.65–10.96)
Experiences of Microsleeps in the Cockpit	**Never**			1.00
	Once			1.45 (.78–2.68)
	Now and Then/Rarely			1.41 (.88–2.26)
	Often			2.41 (1.34–4.35)
	Constant	.579	.338	.118
χ^2 test for model coefficients		14.338 (6df)	28.030 (17df)	136.310 (26df)

4.2.5 Discussion

Based on the findings of the survey, differences in European-registered commercial airline pilots' self-reported depression or anxiety were associated with hours spent on duty. Pilots typically spending longer hours on duty were progressively more likely to report feeling depressed or anxious. Pearson's chi-square test demonstrated that as number of hours on duty increased, self-reported depression or anxiety significantly increased. However, this finding was only significant for pilots working 36 to 40 hours after which the likelihood of reporting depression or anxiety progressively decreased.

These differences in self-reported depression or anxiety were confirmed using binary logistic regression (Model 1). Respondents who typically spend longer hours on duty per week revealed a progressively significantly greater probability of reporting depression or anxiety up to 41 to 45 hours on duty compared with those participants who typically spend less than 25 hours on duty per week. A somewhat similar trend was found by Virtanen and colleagues (2011; Virtanen, Stansfeld, Fuhrer, Ferrie, & Kivimäki, 2012) who studied British public servants for 5.3 to 5.8 years to determine the risks of depressive symptoms and major depressive episodes, respectively. Both studies found that those individuals with long work hours (more than 11 hours per day) showed increased risk of depressive symptoms/major depressive episodes compared with those who worked 7 to 8 hours per day. The results from this study revealed a similar trend, but surprisingly those who reported typically spending more than 50 hours on duty per week, despite being 1.8 times more likely to report feeling depressed or anxious, were not found to significantly differ in their reported feelings of depression or anxiety compared with those who typically spend less than 25 hours on duty per week. Åkerstedt and colleagues (2002) found similar results. They examined the relationship between work, disturbed sleep, and fatigue in an open cohort study with repeated national cross-sectional surveys. Overtime work was not found to result in significant sleep disruption. However, most overtime was found to be voluntary which may thwart adverse sleep effects through selection of those most tolerant of overtime work (Åkerstedt et al., 2002). It is perhaps plausible that the same concept can be applied in this instance in that a positive correlation existed between hours on duty and self-reported feelings of depression or anxiety to a certain point after which those spending long hours on duty (i.e., more than 50 hours per week) may predominantly do so on a "voluntary" basis and as such are more acquiescent of their work practices and thus less inclined to report feelings of depression or anxiety.

In the current study, the findings of Model 2 suggest that the differences in self-reported depression or anxiety associated with typical duty hours are not explained by pilots' demographic characteristics (e.g., position or employment). The binary logistic regression analysis for Model 2 found that differences in the likelihood of reporting feeling depressed or anxious remained constant across differing duty hours of respondents. The recorded difference in self-reported ratings of depression or anxiety were slightly reduced but not fully explained by respondents' individual demographic characteristics thus suggesting that using these pilot demographic characteristics as potential screening markers to identify pilots most susceptible to developing depression or anxiety is not warranted.

Gender and age were the only demographic characteristics found to significantly influence perceived depression or anxiety in Model 2. Gender had a substantial effect on perceived depression or anxiety for females who were 2.6 times more likely to report feeling depressed or anxious than their male counterparts (OR = 2.61, 95% CI = [1.12, 6.07]). According to Nolen-Hoeksema (2001), from adolescence though adulthood, women are twice as likely to experience depression as men. Furthermore, long work hours may pose a higher risk for depression and anxiety among females because women often have added burdens of extended work hours and domestic chores, an explanation for this finding (Artazcoz, Borrell, & Benach, 2001; Gjerdingen, McGovern, Bekker, Lundberg, & Willemsen, 2001; Lundberg & Hellström, 2002; Matthews & Power, 2002). In addition, Baum, Newman, Weinman, West, and McManus (1997) concluded that in community-based surveys, women are more likely to report psychological distress and depression than men. However, caution is warranted due to the number of respondents (31 females vs. 670 males in total).

Age also had an impact on perceived depression or anxiety; older respondents are progressively more likely to report depression or anxiety (those aged 46-55 years were significantly more likely to report feeling depressed or anxious) with the exception of those workers aged 56 to 65 years who were less likely to report feeling depressed or anxious compared with those workers aged less than 25 years. According to a report conducted by the Health and Safety Executive (HSE) in 2002 in the United Kingdom, older workers are more likely to report work-related stress, depression, and anxiety than younger workers, which may be explained by cumulative exposure to workplace hazards such as inadequate work design and management.

When details of respondents' experiences of job-related sleep disturbance and fatigue were included in the binary logistic regression analysis for Model 3, all of the differences across duty hours for self-reported feelings of depression or anxiety disappeared. Indeed, only female respondents remained significantly more likely to report feeling depressed or anxious than the baseline male group. Significant age-group differences were eradicated and overall differences across age were reduced with the inclusion of job-related sleep disturbances and fatigue in the logistic regression analysis (Model 3). These findings suggest that reducing pilots' job-related sleep disturbances and experiences of fatigue may influence the effects of aging on pilots' perceived depression or anxiety. Insufficient sleep has previously been associated with increased risk of psychiatric disorders (Vandeputte & de Weerd, 2003). Similarly, the present study found that sleep disturbances several times per month or per week, resulting from pilots' inability to adopt normal sleeping patterns that promote proper rest due to work schedules, nearly doubled and tripled, respectively, the respondents' probability of reporting depression or anxiety, highlighting the strong association between these two variables. Raggatt (1991) found sleep disturbances among long-distance coach drivers, due most notably from long hours at the wheel (50 hours or more per week), were consistently correlated with stress outcomes and negative health consequences. Furthermore, Raggatt (1991) suggested that fatigue is expressed in a cyclical pattern in which attempts to deal with long hours increases the likelihood of maladaptive coping efforts, resulting in disturbed sleep, fatigue, and eventually stress outcomes.

Pilots' fatigue in the cockpit was found to significantly influence perceived depression or anxiety. Respondents who reported rarely feeling too tired or fatigued in-flight, and those who reported often feeling too tired or fatigued in-flight and felt they should not be on active duty in the cockpit, were 2.3 and 5.3 times more likely to report feeling depressed or anxious, respectively, compared with those who reported never experiencing feelings of being so tired or fatigued in-flight they felt they should not be on active duty in the cockpit. In addition, those who reported often experiencing a microsleep event or falling asleep while on duty in the cockpit without prior agreement with the other pilot were more than twice as likely to report feeling depressed or anxious compared with those who reported never experiencing a microsleep event or falling asleep while on duty in the cockpit. The findings suggest that pilots who spend longer hours on duty and report more frequent feelings of fatigue and microsleeps in the cockpit are significantly more likely to report feeling depressed or anxious. These findings appear to be in consonance with the literature with increasing duty hours associated with increasing feelings of fatigue (Goode, 2003; O'Hagan, Issartel, Fletcher, & Warrington, 2016). According to Ono, Watanabe, Kaneko, Macsumoto, and Miyako (1991), long flight hours and night-time and early morning work significantly contributed to high levels of fatigue complaints among Japanese flight attendants. Fatigue and microsleep events may cluster such that individuals who are more fatigued are more likely to experience microsleep events (Samel et al., 1997; Sirois et al., 2009). Furthermore, fatigue is regularly found to be positively associated with depression and anxiety in both healthy populations and in shift workers (Belza, 1995; Smith et al., 1999) thus further promoting the sentiments of Raggatt (1991) referred to above.

Several study limitations were identified. First, observations were based on self-report rather than objectively measured sleep and fatigue experiences and ratings of depression or anxiety. Self-report research can be biased by potential misunderstanding of posed questions, social desirability as well as cognitive difficulties associated with recall (Sallis & Saelens, 2000; Stone et al., 2009). Moreover, baseline or clinical levels of depression and anxiety were not pre-determined. The present study did not employ a validated measure of depression or anxiety however, various measures do exist and should be considered for future research such as the Beck Depression Inventory (BDI) (Beck et al., 1961), the Zung Self-Rating Depression Scale (Zung, 1965) or the Center for Epidemiologic Studies Depression Scale (CES-D) (Radloff, 1977). Further study employing validated measures would permit researchers to establish a causal relationship between perceived depression or anxiety, duty hours, and experiences of job-related fatigue and sleep disturbance.

Implications of the Research

The findings of this study suggest that differences in self-reported depression or anxiety associated with duty hours are prevalent among European-registered commercial airline pilots with those who spend longer hours on duty being more likely to report depression or anxiety. Demographic factors such as position, employment, contract, or living situation do not appear to explain these differences, therefore, suggesting that using these pilot demographic characteristics as potential screening markers to identify pilots most susceptible to developing depression or anxiety is not supported. However, pilots' experiences of job-related fatigue and sleep disturbance do explain why pilots who typically spend long hours on duty each week are more likely to report feeling depressed or anxious. These findings warrant further investigation into workers job-related fatigue and sleep disturbance issues due to their influential impact on mental health and work safety, not only within an aviation domain but also among those in medicine and nursing where worker performance has a direct and substantial impact on others.

4.2.6 Conclusion

Differences in self-reported depression or anxiety associated with duty hours were found among European-registered commercial airline pilots. These differences cannot be fully explained by demographic characteristics. Differences in perceived depression or anxiety appear to be explained further by job-related fatigue and sleep disturbance. Due to the detrimental and dangerous influence mental health issues can have on work, flying performance, and thus flight safety, further investigation is essential to determine how to identify, monitor, treat, and reduce factors which may negatively influence mental health. Although this study assessed whether job-related fatigue and sleep disturbances could explain the differences in perceived depression or anxiety associated with duty hours, the study did not explore which of these factors (e.g., scheduling, circadian rhythms, workload) contribute to the relationship among duty hours, depression, and anxiety. Further research into these factors and ways in which to positively target these pilot experiences is needed. Moreover, the development and implementation of objective measures of sleep and fatigue could support and validate this study's findings.

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Applying Research to Practice

Pilots who typically spend longer hours on duty per week are more likely to report depression or anxiety. Demographic characteristics such as position, employment, or living situation do not explain why pilots who spend longer hours on duty are more likely to report feeling depressed or anxious. Pilots who report regular sleep disturbances and fatigue in the cockpit are more likely to report feeling depressed or anxious the longer they are on duty.

4.3 Link Section from Chapter 4 to Chapter 5

The findings from the research conducted so far (Study 1 and Study 2) provide great cause for concern regarding sleep loss and fatigue which were found to be widespread within Irish cockpits. Subjective findings concluded that sleep disruption and fatigue are associated with incidents in flight and also with self-reported depression or anxiety among commercial airline pilots. The frequency and magnitude, as well as the consequences, of sleep disruption and fatigue reported in Irish cockpits, warrant further investigation in to the objective impact of these variables on pilots' performance. Therefore, this research further explored the impact of sleep loss and fatigue on commercial airline pilots' aviation-specific competencies and flying performance. These findings aid in providing more detailed objective information pertaining to the full implications and subsequent consequences of sleep deprivation and fatigue on pilot performance in the cockpit in turn leading to the promotion of a safer aviation environment.

Whilst several studies have been conducted in a military aviation setting, to the knowledge of the authors, no previous research has investigated sleep deprivation, fatigue and objective flying performance among commercial airline pilots. Two previous studies (Neri et al., 2002, Roach et al., 2006) did utilise flight simulators in their investigations but did not analyse flying performance. Furthermore, no known prior research has focused on aviation-specific competencies in order to determine how sleep loss and fatigue impact aviation-specific tasks (as opposed to general cognitive function). Study 3 employed tasks and competencies that are of real-world relevance which are specifically applicable to a commercial aviation environment.

Due to the complexity of such a study, it was decided a pilot study would be conducted in the first instance. Findings from Study 3 further promoted the understanding of sleep deprivation on aviation-specific competencies as well as aided in trialling different components of the testing protocol in order to determine their feasibility for future research among professional pilots. Such endeavours ensured successful and relevant data collection and analysis in further studies. Gaining a greater understanding and knowledge of the effects of sleep deprivation and fatigue on airline pilot competencies aids in its' effective management thus reducing risk and enhancing safety.

Chapter 5

Study 3

5.1 Overview of Study 3

Sleep disruption and fatigue is a prevalent issue among pilots in Irish cockpits which can have very serious consquences as was identified from subjective research in Study 1 and Study 2. Sleep deprivation can manifest itself in numerous ways. It can have a highly detrimental effect on everyday acitivies and increase the likelihood of human-error related accidents (Dinges, 1995). Sleep loss and fatigue can result in significant cognitive, motor and neurobehavioral impairments (Waters & Bucks, 2011) which, in an aviation environment, can have catastrophic outcomes. According to the research, sleep deprivation is associated with reductions in vigilance and attention, mood disturbances, impairments in problem-solving and decision-making and declines in working memory (Alhola & Polo-Kantola, 2007; Durmer & Dinges, 2005). However, existing research on the impact of sleep loss and fatigue on occupation-specific competencies, such as those in aviation, is sparse meriting further research is this area.

A somewhat limited number of studies have previously investigated the impact of sleep deprivation and fatigue in a commercial aviation setting with no prior studies investigating the impact of sleep deprivation and fatigue on commercial airline pilots flying performance thus warranting this initial pilot study. This study, which addressed Secondary Objective 2, investigated the impact of 24 hours sleep deprivation on mood, fatigue and airline pilot competencies, specifically cognitive flexibility, working memory, situation awareness and hand-eye coordination among a group of university level students. Analogue measures of these pilot competencies were employed in this repeated measure cross-over design study. Furthermore, a basic computerised flight simulator task was employed. This pilot study not only provided an opportunity to further explore the impact of sleep deprivation and fatigue on pilot competencies, but it also allowed for evaluation and analysis of study design, facilities, equipment and task measures.

By determining appropiate, feasible and viable testing protocols and measures, this study aids in ensuring the development of efficient, appropiate and achievable testing practices prior to conducting a full-scale investigation in to the effects of sleep deprivation and fatigue on pilot performance in the cockpit. Furthermore, enhancing our understanding of the influence and impact of sleep loss and fatigue helps to make better informed decisions regarding its effective management, thus reducing risk and enhancing safety.

5.2 Study 3 – A Pilot Study Exploring the Effects of Sleep Deprivation on Analogue Measures of Pilot Competencies

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Statement of Contribution: Dr. Johann Issartel and Dr. Giles Warrington were involved in the supervision of this study. Mr. Eoghan McGinley was involved in data collection and analysis.

5.2.1 Abstract

Sleep loss can result in cognitive, motor and neurobehavioral impairments. In an aviation context, this can cause a serious threat to flight safety. Therefore, the study aimed to investigate the effects of 24-hours sleep deprivation on mood, fatigue and airline pilot competencies. Seven subjects attended two 24-hour testing periods, one with an 8-hour sleep opportunity, and the other with no sleep opportunity (i.e. sleep deprivation). Subjects were required to complete a battery of mood, fatigue and analogue measures of pilot competency tasks every 8 hours (0 h, 8 h, 16 h, 24 h) throughout each testing period. Whilst total mood disturbance was found to significantly increase (83.42, SD=25.7), both objective (352.71, SD=42.00) and subjective (34.85, SD=8.82) fatigue were found to significantly decrease following 24-hours sleep deprivation. Cognitive flexibility (757.45, SD=58.48) and hand-eye coordination (dominant hand only) (60.28, SD=3.86) were also negatively impacted following 24-hours sleep deprivation. However, working memory and situation awareness were not significantly negatively impacted by the bout of sleep deprivation. Some pilot-specific task related factors such as subjective fatigue, cognitive flexibility and working memory were found to be particularly susceptible to sleep loss with significant declines in performance observed following 16-hours continuous wakefulness suggesting reductions in optimal functioning following this period of wakefulness. Further investigation utilising more regular testing time points, employing additional pilot competencies and more aviation-specific tasks is warranted.

Keywords: Fatigue, Aviation, Pilot Performance, Cognitive Function, Flight Safety

5.2.2 Introduction

Sleep is a fundamental component of human life. Although a full understanding of the functions and purpose of sleep remain unknown, it is clear that it plays a vital role in the restoration of physical and mental functioning. Furthermore, it has been well established that sleep loss and sleep deprivation can result in significant cognitive, motor and neurobehavioral impairments (Waters & Bucks, 2011). According to the research, sleep deprivation is associated with a decline in attention and vigilance, greater negative mood disturbances, slower reaction times, reductions in decision-making and a decline in working memory (Caldwell, 1997; Scott, McNaughton, & Polman, 2006). Several reviews and meta-analyses have been published summarising these research findings (Alhola & Polo-Kantola, 2007; Durmer & Dinges, 2005). However, existing research investigating the effects of sleep deprivation on occupation-specific competencies within certain working industries, such as the aviation domain, are sparse meriting further research in this area.

While previous sleep research has been conducted within the field of aviation and performance (Caldwell, 1997; Lopez et al., 2012), studies investigating the impact on pilot skills and performance have been somewhat limited. Some studies have investigated the impact of sleep deprivation on occupation-specific skills in certain professions such as doctors (Grantcharov et al., 2001), commercial drivers (Bloomfield, Harder, & Chihak, 2009) and military personnel (Russo et al., 2005). According to research conducted by Grantcharov and colleagues (2001), surgeons-in-training who experienced sleep deprivation took significantly more time to complete a virtual laparoscopic surgery, made significantly more errors and had significantly more unnecessary movements during the surgery tasks. Additionally, in a study conducted by Bloomfield, Harder & Chihak (2009), following 20 hours' sleep deprivation, commercial vehicle drivers steering performance was impaired while both steering instability and driving speed significantly increased. In contrast, a full scientific understanding of the impact of sleep deprivation on commercial airline pilot competencies still remains unknown. Any industry which operates 24-hour activities is highly susceptible to human error as a result of sleep deprivation therefore, it is important to be aware of the influence of sleep loss on those workers occupation-specific competencies.

According to the International Civil Aviation Organisation's (ICAO) manual of evidence-based training, which is intended to provide guidance to Civil Aviation Authorities (CAA), operators and approved training organisations, there are 8 core pilot competencies. These core competencies are defined as a group of related behaviours, based on job requirements, which describe how to effectively and proficiently perform a job (2013). They are: Application of Procedures, Communication, Problem Solving and Decision-Making, Situation Awareness, Aircraft Flight Path Management – Automation, Aircraft Flight Path Management – Manual Control, Leadership and Teamwork, and Workload Management. (A detailed description and behavioural indicator of each competency is included in the 2013 ICAO Manual of Evidence-Based Practice).

According to the ICAO manual (2013), problem solving and decision-making are described as the ability to accurately identify risks and resolve problems as well as use appropriate decision-making processes. Pilots are often required to innovatively respond to unique problems, novel task demands and make timely and correct decisions in chaotic situations (Adams, 1993). Therefore, pilots must be able to successfully traverse from thinking about one concept (e.g. calculating how long they can remain in the hold for diversion to a new alternate) to another (e.g. intercepting the localiser), a multi-tasking skill which relies heavily on their cognitive flexibility. Furthermore, according to the problem solving and decision-making behavioural descriptor, pilots must also be able to monitor, review and adapt decisions as required, all while working through problems without reducing safety. Pilots are required to sense, organise and use information resulting in the use of resources from both their short-term and long-term memory systems (Adams, 1993). This requires pilots to have an excellent functioning working memory. As well as being able to solve complex problems in high pressure and demanding situations, pilots must also be able to maintain excellent awareness of themselves and the environment around them. Situation awareness is the ability to perceive and comprehend all relevant information available and anticipate what could happen that may affect the operation. It is considered a basic requirement of good airmanship and forms the basis for pilot decision-making and performance (Endsley, 1999).

In addition to spatial awareness, hand-eye coordination is an additional competency which is vital for airline pilots to allow for successful operation and navigation of the aircraft. In order to successfully operate an aircraft, a pilot requires high levels of perceptive, cognitive and motor ability to ensure appropriate reaction to changing environments and situations. Precision of movement is vital to ensure the successful execution of fine motor skills, for which such skills are required for numerous actions associated with the trim control or switches (Pipraiya & Chowdhary, 2006).

Air travel is growing in popularity year by year resulting in today's flight operations and pilots working pressurised 24/7 timetables. The unrelenting escalation in international long-haul, short-haul, regional and overnight operations will continue to increase these round-the-clock requirements which pose a potential threat to human error over time as a result of sleep deprivation. As such, it is important to question to what extent and at what point in time are pilots' competencies impaired by sleep loss. The ecological validity of this question is highlighted by sleep/fatigue-related aviation disasters including the the 1997 Korean Air flight 801 crash in which 228 people died, the 1999 the American Airlines flight 1420 accident which claimed 11 lives, and the 2004 Corporate Airlines Flight 5966 crashed on its approach to Kirksville Regional Airport killing 11 of its 13 passangers and 2 crew.

The potential risks of sleep loss and sleep deprivation have previously being somewhat demoted by society regardless of evidence highlighting the increased threats to health and safety. As a result, greater information pertaining to the full implications and subsequent consequences of the effect of sleep deprivation and fatigue on performance is required. The aim of this study was therefore to investigate the effect of 24-hours sleep deprivation on mood, fatigue and airline pilot competencies, specifically cognitive flexibility and working memory (indicators of the problem solving and decision-making core competency), situation awareness and motor and hand-eye coordination. Determining the effects of sleep deprivation on airline pilot competencies will aid in its effective management thus reducing risk and enhancing safety.

The present study contained several key limitations which should be noted now. Firstly, due to the pilot nature of this research, seven university levels students, as opposed to commercial airline pilots were recruited to take-part in this research. Secondly, this study employed analogue, as opposed to direct, measures of airline pilot core competencies some of which were subjective and not aviation-specific in nature. Whilst these factors act as potential limiters of this research, it did measure cognitive skills which are required and utilised during real-world flying tasks.

5.2.3 Methods

5.2.3.1 Subjects

A convenience sample comprising of seven male university level subjects (age 21 $\pm$ 1 years, height 182.01 $\pm$ 7.71cm, body mass 83.27 $\pm$ 9.64kg), who are part of the School of Health &

Human Performance and were not qualified pilots, were recruited to participate in this study. All subjects were non-smokers, not presently taking any form of medication and refrained from alcohol and heavy exercise for the 24-hours prior to each testing protocol. None had previously engaged in sleep deprivation studies or reported sleep disorders as determined by the SLEEP-50 questionnaire. They also maintained normal sleeping and eating habits for the 72-hours prior to each testing protocol. Subjects were not permitted to ingest any caffeine and were provided with all meals by the researchers during each testing session. Prior to any data collection, ethical approval was granted by Dublin City University Ethical Committee (Appendix D). All subjects provided written consent prior to participation (Appendix E & F).

5.2.3.2 Measures

Table 5.1 contains an overview of the variables under investigation and the analogue measures employed in the present study.

Table 5.1. Overview of the Variable and Measures Used

	Variable	Measure
Mood	Subjective Mood	Profile of Mood States
Fatigue	Subjective Fatigue	Fatigue Severity Scale
	Objective Fatigue	Psychomotor Vigilance Task
Airline Pilot Competencies	Cognitive Flexibility	Stroop Colour & Word Test
	Working Memory	Auditory Digit Span Test
	Situation Awareness	Situation Awareness Rating Technique
	Hand-Eye Coordination	Grooved Pegboard

Mood state was assessed using the Profile of Mood States Questionnaire (POMS). POMS is a 65-item scale which has been proven to be valid among healthy adult populations and has a high internal consistency. A seventh score of Total Mood Disturbance (TMD) was also calculated with this measure.

Subjective fatigue was measured using the Fatigue Severity Scale (FSS). The FSS has been found to be a simple yet reliable instrument for measuring subjective fatigue and has also been shown to have high internal consistency and good test-retest reliability.

Objective fatigue was determined using the Psychomotor Vigilance Task (PVT). This 10-minute visual psychomotor task was conducted on the PC-PVT v1.1.0 which has been shown to compare favourably to the gold standard PVT-192 device. Mean reaction time (MRT) was recorded along with lapses in attention (a response time of >500ms).

Cognitive flexibility was determined by the Stroop Colour and Word Test (SCWT) measured using Inquisit 4 Web (Millisecond Software). The Stroop Test has been found to be reliable and one of the best and most used measures of inhibitory processes and cognitive flexibility.

Working memory was determined using the Auditory Digit Span (Forward & Backward) Test (ADS) of the Wechsler Adult Intelligence Scale – Fourth Edition. This test is one of the oldest and most widely utilised neuropsychological tests of working memory. The raw score for the maximum number of digits recalled was used as the outcome measure in both the forward and backward trials. The test ceases when the participant fails to accurately recall either trial at one sequence length or when the maximal list length is reached (9 digits forward, 8 digits backward).

Situation awareness was assessed using the Situation Awareness Rating Technique (SART) which was completed following performance of a computerised flight simulator task on a YSFlight Simulator (Version 20130805) (Appendix G). This is a simplistic post-trial subjective rating measure which was originally developed to assess pilots' situational awareness. Subjects were required to land an aircraft using a pre-set scenario following which they were required to complete the SART.

Hand-eye coordination was determined using the Grooved Pegboard (GPB) test (Lafayette Instrument, Model 32025, Lafayette). This is a test of hand-eye coordination and motor speed which requires sensory motor integration and a high level of motor processing.

5.2.3.3 Procedure

This study employed a repeated measures crossover design with subjects acting as their own controls. Habituation testing was followed by two 24-hour testing periods (one with an 8-hour sleep opportunity and the other with no sleep opportunity (i.e. sleep deprivation)). Each testing period was separated by a minimum of 7 days to allow for sufficient rest and recuperation. Subjects were randomly assigned to their order of testing. Subjects were familiarised with the experimental tests and procedures during their initial visit to the laboratory. In all instances, familiarisation testing took place four days prior to the first data collection period. Due to availability of facilities and equipment, data collection for individual subjects commenced at 60-minute intervals beginning at 0700 h or 0800 h. Sleep and waking schedules were manipulated to ensure all subjects were tested at the same points post-waking throughout each testing period. The testing protocol and procedure was identical during both the 'sleep' and 'no sleep' testing periods. Subjects were instructed to wake 30-minutes prior to their scheduled start time after approximately 8 hours sleep, and report to the laboratory immediately.

Each testing period consisted of four identical testing sessions which were performed every 8 hours (0 h, 8 h, 16 h, 24 h). The duration of each testing session lasted for 60 minutes and consisted of a battery of mood (Subjective Mood), fatigue (Subjective Fatigue and Objective Fatigue) and analogue measures of airline pilot competencies (specifically Cognitive Flexibility and Working Memory (indicators of the Problem Solving and Decision-Making core competency), Situation Awareness, and Hand-Eye Coordination).

During free time, subjects engaged in sedentary activities including reading, watching TV and playing cards. The investigators maintained constant vigilance over subjects, and if dozing was identified, subjects were gently but quickly awoken. Subjects remained in the laboratory for the full duration of both testing periods with full sleeping facilities provided during the 'sleep' condition.

5.2.3.4 Statistical Analysis

All statistical analysis was performed using SPSS Version 23 (SPSS Inc.). A 2X4 repeated measure ANOVA within-subject design was carried out to determine whether there was a significant difference between all tests (mood, fatigue and airline pilot competencies) at the different time points (0 h, 8 h, 16 h, 24 h) (please see footnotes[8] for non-parametric Friedman Tests for all repeated measures ANOVA due to small sample size). Post hoc analysis using a Bonferroni test was used to identify where these differences lie. In instances where Mauchly's

[8] *Due to potential violations of non-normality as a result of a small sample size, Friedman tests were run. Friedman Findings: POMS-Tension,* $\chi^2(7)=7.989$, $p=.334$; *POMS-Depression,* $\chi^2(7)=19.395$, $p<.01$; *POMS-Anger,* $\chi^2(7)=16.563$, $p<.05$; *POMS-Fatigue,* $\chi^2(7)=27.182$, $p<.001$; *POMS-Vigour,* $\chi^2(7)=25.857$, $p<.001$; *POMS-Confusion,* $\chi^2(7)=26.853$, $p<.001$; *Total Mood Disturbance,* $\chi^2(7)=29.675$, $p<.001$; *Fatigue Severity Scale,* $\chi^2(7)=17.691$, $p<.05$; *PVT: Lapses in Attention,* $\chi^2(7)=19.309$, $p<.01$; *PVT: Mean Reaction Time,* $\chi^2(7)=21.334$, $p<.01$; *Stroop Test: Control,* $\chi^2(7)=7.190$, $p=.409$; *Stroop Test: Congruent,* $\chi^2(7)=14.429$, $p<.05$; *Stroop Test: Incongruent,* $\chi^2(7)=23.095$, $p<.01$; *Auditory Digit Span Forwards,* $\chi^2(7)=6.119$, $p=.526$; *Auditory Digit Span Backwards,* $\chi^2(7)=3.355$, $p=.850$; *Overall Situation Awareness,* $\chi^2(7)=4.084$, $p=.770$; *GPB: Dominant Hand,* $\chi^2(7)=10.720$, $p=.151$; *GPB: Non-Dominant Hand,* $\chi^2(7)=6.719$, $p=.459$.

test of sphericity was significant, the Greenhouse-Geisser adjusted degrees of freedom were used. Cohen's *d* was also utilised to demonstrate the size of effect between variables means across testing sessions. An alpha value of $p<0.05$ was used to determine statistical significance.

5.2.4 Results

Table 5.2 provides the results for the 2X4 repeated measure ANOVA for each of the dependent variables. (Please see Appendix H for means and SD's of all variables).

Table 5.2. Results of Analysis of Variance for the 2 conditions ('sleep', 'no sleep') by 4 time points (0 hrs, 8 hrs, 16 hrs, 24 hrs)

Dependent Variable	Time Main Effect	Condition Main Effect	Interaction Effect
Mood			
Tension	*F*=0.541; *p*=0.661	*F*=3.891; *p*=0.096	*F*=0.697; *p*=0.566
Depression	*F*=2.384; *p*=0.103	*F*=8.681; *p*=0.026*	*F*=2.941; *p*=0.061
Anger	*F*=2.501; *p*=0.143	*F*=1.156; *p*=0.324	*F*=2.619; *p*=0.082
Fatigue	*F*=15.767; *p*=<0.001***	*F*=7.490; *p*=0.034*	*F*=7.895; *p*=0.001***
Vigour	*F*=14.470; *p*=<0.001***	*F*=1.682; *p*=0.242	*F*=2.330; *p*=0.109
Confusion	*F*=8.686; *p*=0.001***	*F*=2.576; *p*=0.160	*F*=1.848; *p*=0.175
Total Mood Disturbance	*F*=19.232; *p*=<0.001***	*F*=8.615; *p*=0.026*	ƒ*F*=3.887; *p*=0.026*
Subjective Fatigue			
FSS	*F*=3.729; *p*=0.030*	*F*=2.754; *p*=0.148	*F*=3.025; *p*=0.057*
Objective Fatigue			
PVT: Lapses in Attention	ƒ*F*=13.516; *p*=0.006**	*F*=6.198; *p*=0.047*	*F*=8.599; *p*=0.017**
PVT: Mean Reaction Time	*F*=8.214; *p*=0.001***	*F*=2.284; *p*=0.181	*F*=7.511; *p*=0.002**
Problem Solving & Decision-Making: Cognitive Flexibility			
Stroop Test: Control	*F*=6.664; *p*=0.003**	*F*=0.990; *p*=0.358	*F*=1.666; *p*=0.210
Stroop Test: Congruent	*F*=4.044; *p*=0.070	*F*=0.076; *p*=0.792	*F*=0.517; *p*=0.562
Stroop Test: Incongruent	*F*=9.653; *p*=0.001***	*F*=3.097; *p*=0.129	*F*=6.475; *p*=0.004**
Problem Solving & Decision-Making: Working Memory			
Auditory Digit Span Forwards	*F*=0.533; *p*=0.665	*F*=0.287; *p*=0.611	ƒ*F*=1.795; *p*=0.224
Auditory Digit Span Backwards	*F*=0.503; *p*=0.685	*F*=0.079; *p*=0.788	*F*=0.300; *p*=0.825
Situation Awareness			
Overall Situation Awareness	*F*=0.357; *p*=0.785	*F*=0.552; *p*=0.485	*F*=1.134; *p*=0.362
Hand-Eye Coordination			
GPB: Dominant Hand	*F*=1.074; *p*=0.385	*F*=0.069; *p*=0.802	*F*=6.765; *p*=0.003**
GPB: Non-Dominant Hand	*F*=0.972; *p*=0.428	*F*=0.176; *p*=0.689	*F*=0.489; *p*=0.694

An interaction effect was found for both fatigue, $F(3,18)=7.895$, $p=.001$, and TMD, ƒ$F(3,18)=3.887$, $p=.026$ as determined by the POMS. At the 24-hour time point, the 'no sleep' condition reported significantly higher levels of fatigue ($t(6)=-4.885$, $p=.003$) ($d=2.20$) (see Figure 5.1) and significantly greater levels of mood disturbance ($t(6)=-4.488$, $p=.004$) ($d=1.38$)

in comparison to the ‘sleep’ condition. As regards the fatigue subscale, significantly greater levels of fatigue were reported at the 24-hour time point in comparison to the 0-hour (F(3,18)=19.819, p=.009) (d=2.58), 8-hour (F(3,18)=19.819, p=.013) (d=2.91) and 16-hour (F(3,18)=19.819, p=.016) (d=1.66) time points in the ‘no sleep’ condition. Furthermore, TMD increased with increasing time awake with significantly greater TMD reported at the 24-hour time point in comparison to the 0-hour (F(3,18)=15.482, p=.014) (d=1.80) and 16-hour time points (F(3,18)=15.482, p=.019) (d=1.27) in the ‘no sleep’ condition. A significant condition main effect was found for depression, F(1,6)=8.681, p=.026, with significantly greater levels of depression reported at the 24-hour point between the ‘sleep’ and ‘no sleep’ conditions (t(6)=-3.012, p=.024) (d=1.21).

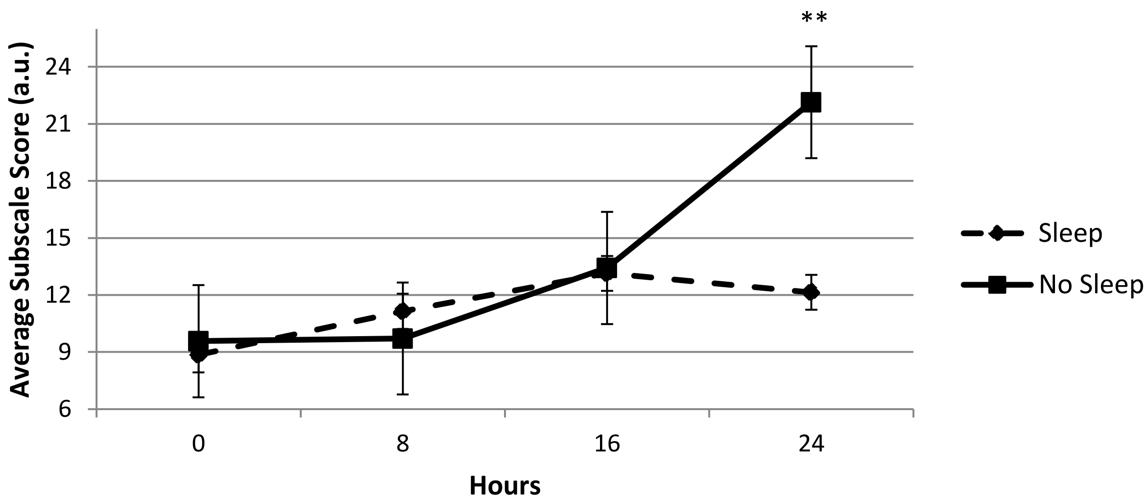

Figure 5.1. Average fatigue subscale scores (±SE) for the ‘Sleep’ and ‘No Sleep’ Conditions. * p<0.05; ** p<0.01; *** p<0.001.

Subjective fatigue revealed an interaction effect F(3,18)=3.025, p=.05. Post hoc comparisons showed significantly higher fatigue scores between the ‘sleep’ and ‘no sleep’ conditions at the 24-hour time point (t(6)=-4.074, p=.007) (d=0.80). Furthermore, subjective fatigue scores were significantly higher at the 24-hour time point relative to the 0-hour time point (F(3,18)=4.132, p=.026) (d=1.01) in the ‘no sleep’ condition.

A 2X2 repeated measures ANOVA was also conducted for the POMS fatigue subscale and the FSS measure between the 16-hour and 24-hour time points between each condition. A significant interaction effect was found for both the POMS fatigue subscale and the FSS measure, F(1,6)=15.046, p=.008 and F(1,6)=6.323, p=.046, respectively. Post hoc comparison showed significantly higher levels of fatigue were reported for the POMS fatigue subscale only between the 16-hour and 24-hour time points during the 'no sleep' condition, ($t(6)=-4.889$, $p=.003$) ($d=1.66$). No significant differences were found between the 16-hour time points across each of the conditions for the POMS fatigue subscale or the FSS measure.

An interaction effect was found for both 'lapse in attention' (response time of >500ms) $F(3,18)=8.599$, $p=.001$ and Mean Reaction Time $F(3,18)=7.511$, $p=.002$ (see Figure 5.2 and Figure 5.3). At the 24-hour time point, the 'no sleep' condition reported significantly more lapses in attention ($t(6)=-3.029$, $p=.023$) ($d=1.57$) and significantly slower reaction times ($t(6)=-2.627$, $p=.039$) ($d=1.49$) in comparison to the 'sleep' condition. Additionally, significantly more lapses in attention were reported at the 24-hour time point in comparison to the 0-hour ($F(1.083,18)=13.001$, $p=.049$) ($d=1.60$) and 16-hour ($F(1.083,18)=13.001$, $p=.039$) ($d=1.75$) time points in the 'no sleep' condition. As regards mean reaction time, significantly slower reaction times were reported at the 24-hour time point in comparison to the 16-hour time point ($F(3,18)=10.299$, $p=.030$) ($d=1.93$) in the 'no sleep' condition.

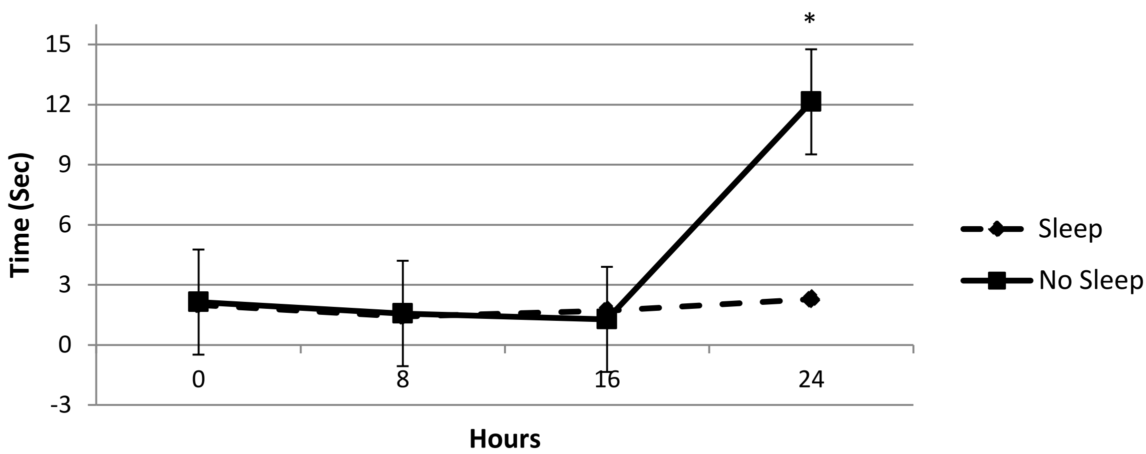

Figure 5.2. Objective Fatigue – Lapses in Attention (±SE) for the 'Sleep' and 'No Sleep' Conditions.

*** p<0.05; ** p<0.01; *** p<0.001**

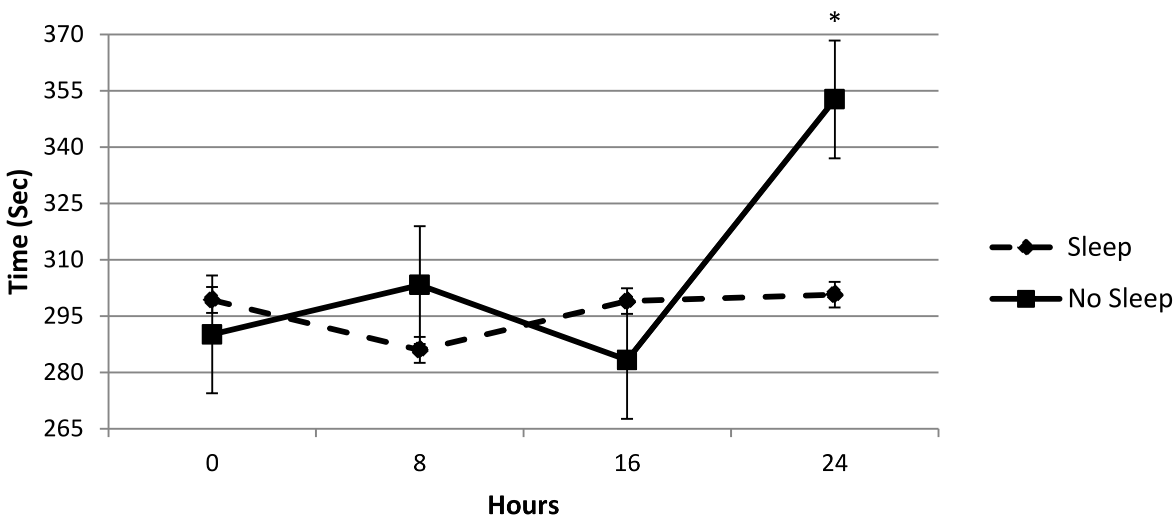

Figure 5.3. Objective Fatigue – Mean Reaction Time (±SE) for the 'Sleep' and 'No Sleep' Conditions.

*** p<0.05; ** p<0.01; *** p<0.001**

The analysis of Stroop Test reveals a significant interaction effect for the incongruent trials, $F(3,18)=6.475$, $p=.004$. As can be seen in Figure 5.4, response times in the incongruent trials were significantly slower at the 16-hour time point ($t(6)=-3.061$, $p=.022$) ($d=1.58$) and the 24-hour time point ($t(6)=-3.169$, $p=.019$) ($d=1.56$) in the 'no sleep' condition versus the 'sleep' condition. Furthermore, in the incongruent trials, significantly faster response times were recorded at the 8-hour time point ($F(3,18)=10.578$, $p=.012$) ($d=2.24$) and the 16-hour time point ($F(3,18)=10.578$, $p=.038$) ($d=1.59$) in comparison to the 24-hour time point in the 'no sleep' condition.

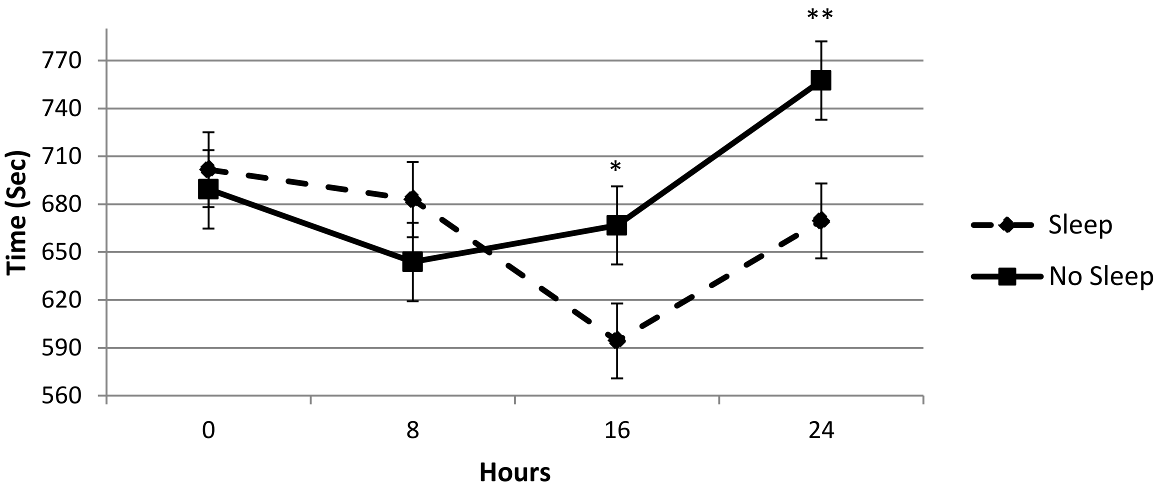

Figure 5.4. Problem Solving & Decision-Making – Stroop Test: Incongruent Trial (±SE) for the 'Sleep' and 'No Sleep' Conditions.

*** p<0.05; ** p<0.01; *** p<0.001**

The cost of the Stroop effect (i.e., the incongruent trials – the congruent trials) was also calculated (Figure 5.5). No significant interaction effect, condition main effect or time main effect was found.

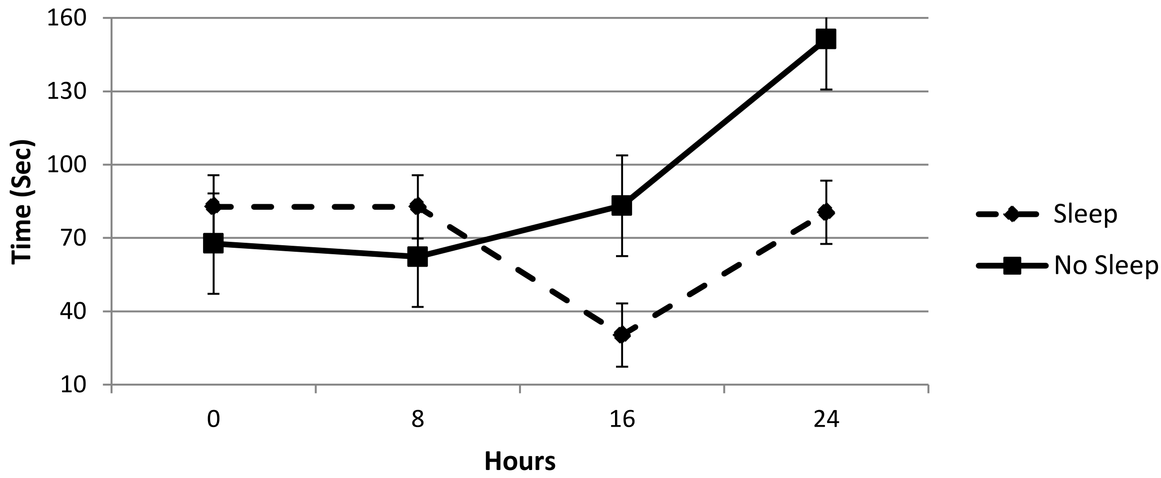

Figure 5.5. Problem Solving & Decision-Making – Stroop Test: Cost of the Stroop Effect (Incongruent Trials – Congruent Trails) (±SE) for the 'Sleep' and 'No Sleep' Conditions.

No significant interaction effect was found for the ADSF *(†F*(3,18)=1.795, *p*=.022), the ADSB *(F*(3,18)=0.300, *p*=.082) or for situational awareness in the computerised flight task *(F*(3,18)=1.134, *p*=.036).

With regard to the GPB, an interaction effect was found for the dominant hand only, *(F*(3,18)=6.765, *p*=.003). At the 24-hour time point, the 'sleep' condition recorded significantly faster times in comparison to the 'no sleep' condition (*t*(6)=-2.948, *p*=.026) (*d*=1.51) (see Figure 5.6). No significant differences across the time points were identified, although trends indicated that subjects got slower following the period of sleep deprivation.

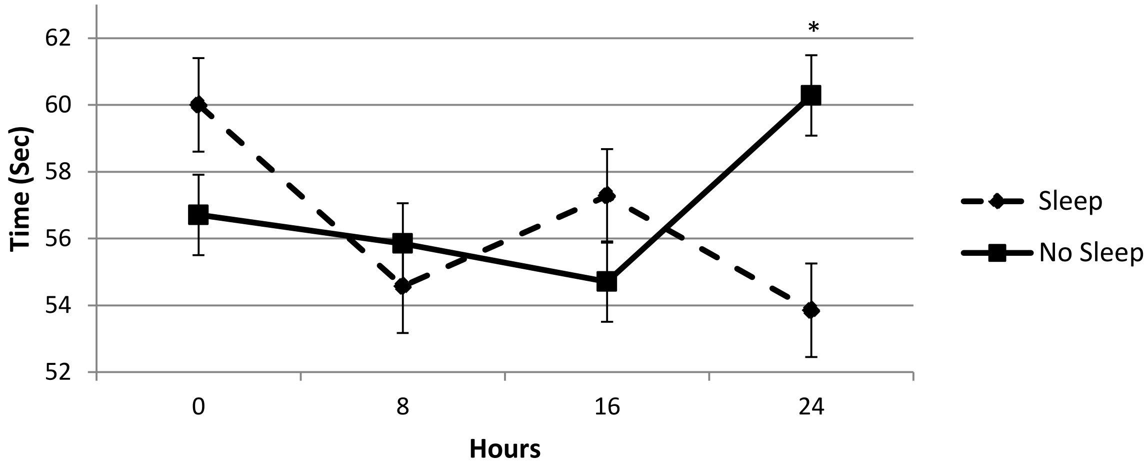

Figure 5.6. Hand-Eye Coordination – GPB: Dominant Hand (±SE) for the 'Sleep' and 'No Sleep' Conditions.

*** p<0.05; ** p<0.01; *** p<0.001**

5.2.5 Discussion

The purpose of this study was to investigate the effects of a period of sleep deprivation on mood, fatigue and airline pilot competencies, specifically cognitive flexibility and working memory (indicators of the problem solving and decision-making core competency), situation awareness and hand-eye coordination among a group of university level students who were not qualified pilots. The main findings concluded that self-reported mood and both subjective and objective fatigue were significantly negatively impacted by 24-hours sleep deprivation. As regards pilot competencies, analogue measures of these skills found that cognitive flexibility and hand-eye coordination (dominant hand only) significantly declined with increasing time awake. However, both working memory and situation awareness were not found to be significantly negatively impacted by the period of sleep deprivation.

Both fatigue and TMD significantly increased with increasing time awake. These results are in line with previous findings (Durmer & Dinges, 2005; Sagaspe et al., 2006). Current research suggests that there is an association between increased negative moods and sleep deprivation regardless of whether sleep deprivation is chronic or acute in nature. Furthermore, self-reported depression was significantly increased following 24-hours sleep deprivation. It has been suggested that the interacting effects of depression could moderate additional mood states and performance. Preliminary research suggests that a depressed mood could decrease vigour and negatively influence all the other mood state variables (Scott, McNaughton, & Polman, 2006).

Subjective fatigue was also found to significantly increase with increasing time awake with significant increases in subjective fatigue identified following 24-hours sleep deprivation. It is widely agreed that sleep deprivation increases feelings of fatigue and insufficient sleep is considered one of the key factors which contribute to tiredness and sleepiness (Sagaspe et al., 2006). Objective fatigue findings appeared to very closely coincide with subjective findings. Both lapses in attention and mean reaction time on the PVT were significantly increased following 24-hours sleep deprivation. According to Doran and colleagues (2001) 'state instability' hypothesis, as loss of sleep continues, performance variability increases in a way which is reflective of the interaction of the homeostatic drive for sleep and the internal circadian drive for wakefulness, and the compensatory effort displayed by subjects to maintain performance. This hypothesis posits that following a substantial period of sleep loss, normal responses are not sustainable over time, despite compensatory effort, due to sleep initiation processes chronic intrusion into wakefulness.

Subjects' ability to successfully switch from one response set to another (i.e. their cognitive flexibility) was found to decline with increasing time awake with slower response times recorded following 24-hours continuous wakefulness. Stimulating and short-duration executive tasks which involve the prefrontal cortex, such as planning, decision-making and divergent thinking (i.e. skills which are dependent on spontaneity, creativity and flexibility) are proposed to be sensitive to total sleep deprivation. However, not all results are in accordance with the proposed impact of sleep deprivation on executive functions, notably that of Binks and colleagues (1999) who did not find an effect for short-term sleep deprivation on a Stroop task. In the present study, cognitive flexibility was one of the first measures to be significantly negatively affected by sleep deprivation. Further investigation is needed to determine its potential as a precursor of sleep disturbance or sleep loss.

With regards to working memory, no significant declines in performance were found following the period of sleep deprivation. According to Waters & Bucks (2011), findings have been mixed regarding the effects of sleep deprivation on auditory, visual and spatial short-term memory tasks. Some studies have found impaired digit recall performance following 24-hours sleep deprivation, while others have not. Whilst behavioural findings tend to display mixed results, neuroimaging studies have presented clearer findings (Chee & Chuah, 2007). Chee & Chuah

(2007) found a quantifiable effect on neural functions associated with a visual short-term memory task following 24-hours sleep deprivation. The general decline in short-term memory following the period of sleep deprivation was associated with a reduction in intraparietal sulcus activity which was in turn associated with a reduction in memory capacity. On the whole, it appears loss of sleep has a biological influence on short-term memory capacity which is not always detected via cognitive measures. As this present study did not employ neuroimaging techniques, it cannot conclude if this occurred in this instance.

In 'real-world' scenarios, the most serious consequences of sleep deprivation result from substantial cognitive or attentional failures. These substantial cognitive or attentional failures are often referred to as a loss of situational awareness of which is proposed to be susceptible to sleep deprivation. However, the present study failed to find any significant changes in situation awareness following 24-hours sleep deprivation. This study employed a subjective rating scale to assess situation awareness. However, such subjective measures may only provide insight in to how aware the subject felt they were during the task as opposed to how aware they actually were. An individual's subjective assessment may deviate from their actual situational awareness. Self-rating methods of situation awareness may only indicate a subjects confidence in their situational awareness as opposed to their actual awareness of which is proposed to be impaired by sleep deprivation (Alhola & Polo-Kantola, 2007). Results from the present study should be taken with caution as further research employing alternative methods of measurement is advised.

Hand-eye coordination was also found to be susceptible to sleep deprivation with significant declines in performance, in subjects dominant hand only, observed following 24-hours sleep deprivation. Significant impairments were only observed in the dominant hand, presumably due to poor baseline performance levels in the non-dominant hand masking any additional declines in performance as a result of sleep loss. Previous research has consistently found declines in hand-eye coordination and psychomotor performance with up to 30% reductions observed in speed and accuracy as a consequence of sleep deprivation. One study by Taffinder and colleagues (1998) examined the effect of sleep deprivation on surgical manual dexterity. They found that surgeons who were deprived of sleep made 20% more errors and took 14% longer to complete the tasks relative to those who had a full night's sleep. The present findings suggest that, similar to Taffinder's study among surgeons, airline pilots' manual dexterity is vulnerable to the effects of short-term sleep loss. Furthermore, neuroimaging findings have suggested that normal functioning of the sustained attention network is altered following a period of sleep loss which results in greater disengagement from external sensory input potentially resulting in impairments in hand-eye coordination. The associated decline in sustained attention, as observed with the PVT, may aid in explaining the observed reduction in hand-eye coordination among this study's subjects.

5.2.6 Conclusion

The present study contained several limitations as briefly mentioned in the introduction. Firstly, due to the pilot nature of this study, seven university levels students were recruited to take-part in this study. This limited number of young subjects from non-aviation backgrounds may not be reflective of the commercial airline pilot population. Future research should aim to increase subject numbers and recruit commercial airline pilots to confirm and strengthening findings. Secondly, this study employed analogue, as opposed to direct, measures of airline pilot core competencies some of which were subjective and not aviation-specific in nature. Whilst it did not directly assess pilots' core competencies, it did measure cognitive functions ranging from cognitive flexibility and working memory to vigilance and hand-eye coordination which have direct implications on those skills required by airline pilots to successfully operate an aircraft. Standardised cognitive tests were employed to provoke and identify changes in psychomotor and cognitive functions. The duties and responsibilities of operating an aircraft undeniably require considerably more complex cognitive functions than those posed by these tests. The deteriorations observed in these particular tests may therefore be moderate relative to the actual effects that sleep deprivation may have on cognitive skills required to operate an aircraft. Furthermore, the present study conducted testing sessions every 8 hours. As a result this allowed for a cross-over design, permitting an 8-hour sleeping opportunity during the 'sleep' condition and allowing subjects to act as their own controls. Future research should aim to implement more regular testing time points which will allow for a more detailed indication of potential fluctuations and associated circadian effects throughout the period of sleep deprivation (Alhola & Polo-Kantola, 2007).

Lapses in attention, reductions in vigilance, decreases in mood and cognitive flexibility were all found following 24-hours sleep deprivation and have the potential to negatively impact pilots' performance in the cockpit and contribute to an aviation accident. The results of the present study suggest that subjects were able to maintain a relatively stable performance up to 16-hours continuous wakefulness, which is somewhat replicative of a normal day. However, following this, considerable reductions in mood, fatigue and certain analogue measures of airline pilot competencies (i.e. cognitive flexibility and hand-eye coordination) became evident suggesting reductions in optimal functioning following this period of wakefulness. Further investigation utilising more regular testing time points, employing additional core pilot competencies and using more aviation-specific tasks will aid in supporting and validating the initial findings of this study.

Acknowledgements

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Disclosure Statement

No potential conflict of interest was reported by the authors.

5.3 Link Section from Chapter 5 to Chapter 6

Sleep deprivation and fatigue pose an insidious threat to flight safety. Study 3 investigated the effects of sleep deprivation on mood, fatigue and airline pilot competencies among a group of university level students. Results concluded that following 24 hours' sleep deprivation, objective fatigue, cognitive flexibility and hand-eye coordination were significantly impacted whilst, working memory and situation awareness were not significantly negatively impacted by the bout of sleep deprivation. This pilot study also explored various aspects of the testing protocol, measurement tasks, and testing facilities and equipment prior to undertaking a full investigation with a group of professional pilots. It was concluded that various amendments were needed prior to further investigation among a group of commercial airline pilots.

Study 3 conducted testing every 8 hours in order to allow an 8 hour sleeping opportunity during the normal sleep trial. This was found to be too large a gap and would not give a clear indication to fluctuations in performance and circadian rhythm with increasing time awake. Also, the cross-over design employed in Study 3 would not be feasible when considering the working schedules of professional pilots thus justifying further amendment to the protocol. Additionally, some of the task measures need to be modified in the next study. For example, the SART was used as a measure of situation awareness. However, the subjective nature of this measure may have had an influencing impact and as such it was decided a more objective measure would need to be employed. Moreover, Study 3 employed a basic computerised flight simulator. It was concluded that this would not be a sufficient measure of flying performance due to its simplicity. The use of a specialised flight simulator utilising a commercial-aviation specific flight task would garner the most beneficial and relevant output.

Study 4 advanced on the testing protocol and procedures employed in Study 3 and sought to further investigate the influence of sleep deprivation and subsquent fatigue on airline pilot competencies and objective flying performance. Moreover, Study 4 explored if changes in specific psychological measures and cognitive tests were related to changes in flight performance over the period of continuous wakefulness.

Chapter 6

Study 4

6.1 Overview of Study 4

So far this research has found that sleep disturbance and fatigue are prevalent in Irish cockpits and can have very serious consequences on both pilot health and flight safety. The impact of fatigue and sleep loss and its negative and sometimes calamitous effects are particularly evident within the aviation industry (i.e., the 2004 Corporate Airlines Flight 5966 crash in which 11 people died; the Korean Air flight 801 crash in which 228 people died). Furthermore, the magnitude of sleep and fatigue-related accidents demonstrates the necessity to create adequate preventative and protective measures that alleviate errors caused by sleep loss and associated fatigue (Costa, 2003).

Study 4 further investigated the effects of acute sleep deprivation and subsequent fatigue on mood, pilot-specific competencies and flying performance of commercial airline pilots (Primary Objective 3). Furthermore, this study also addressed Secondary Objective 3 and investigated if changes in psychological and cognitive measures were related to changes in flying performance with increasing time awake.

As determined from Study 3, a basic computerised flight task was not sufficient to objectively measure flying performance in professional pilots. Professional links were created with researchers in the National Aerospace Laboratory (NLR) in Amsterdam who kindly supplied a computerised flight simulator – AIRSIM – for use in the present study. Furthermore, Jeppesen, provided navigational air charts for use in the AIRSIM. To the knowledge of the authors, no previous studies have investigated flying performance of commercial airline pilots in a sleep loss environment and therefore, it was essential to create a flight task from scratch (ultimately taking 15 months to develop). Several studies have been conducted in a military aviation setting which helped to inform this flight task. Furthermore, extensive in-depth discussions with a range of professionals from pilots, researchers and air traffic controllers were involved in the development of this flight task.

This research aids in identifying the influence of sleep deprivation and subsequent fatigue on commercial airline pilots' performance in the cockpit and in highlighting the point at which sleep loss and fatigue begin to significantly impair pilot performance. Additionally, this research explored measures of psychological and cognitive function which may have future use as markers of potential impending precarious situations in the cockpit as a result of sleep loss and fatigue through early detection of impaired flying performance.

6.2 Study 4 – "Flying On Empty" – Effects of Sleep Deprivation on Pilot Performance

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Manuscript submitted for publication.

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Statement of Contribution: Dr. Johann Issartel and Dr. Giles Warrington were jointly involved in the supervision of this study. Mr. Aidan Wall was involved in the development of the study and data collection. Mr. Fritz Dunne was involved in data extraction from the flight simulator.

6.2.1 Abstract

Today's flight operations work on pressurised 24/7 timetables. As a result, sleep loss and fatigue are becoming commonplace among pilots and pose a serious threat to flight safety. This study aimed to examine the effects of 24 hours' sleep deprivation on a variety of psychological measures, cognitive performance tasks and simulated flight. Seven commercial airline pilots completed the Samn-Perelli Crew Status Check (SPC), Profile of Mood States (POMS), Psychomotor Vigilance Task (PVT), Dual-N-Back, Rapid Visual Information Processing Task (RVP), NASA Task Load Index (NASA-TLX) and aviation-specific mathematical calculations as well as a computerised flight simulator task, during which participants were required to answer mid-flight fuel calculations and situational awareness questions (SA). Testing occurred at 3 hour intervals during the final 12 hours of a 24 hour period of continuous wakefulness. Significant impairments in performance were observed on nearly all tests following 20 hours continuous wakefulness. Flying performance was not significantly impaired. Changes in flight performance were found to be consistent with changes in situation awareness. Overall findings showed impairments in mood, cognition and flying performance following 20 hours continuous wakefulness. SA indicates promise as a potential indictor of changes in flying performance as a result of sleep deprivation and fatigue.

Key Words: sleep deprivation; fatigue; mood; cognition; flight performance

6.2.2 Introduction

Consuming almost one-third of our lives, sleep is a vital and complex component which is essential for human functioning (Banks & Dinges, 2007). As a result, sleep loss or sleep deprivation can significantly interfere with and impair cognitive, motor and physiological functioning (Scott, McNaughton & Polman, 2006; Waters & Bucks, 2011). It can also negatively influence one's emotions and mood states. Sleep loss and subsequential fatigue are associated with reductions in cognition (Lieberman et al., 2002), impairments in performance in the workplace (Harrison & Horne, 2000), greater error rates (Gander et al., 2014) and ultimately declines in safety (Åkerstedt, 2003). Sleep deprivation can have a highly detrimental effect on everyday activities, increasing the likelihood of human-error related accidents. Sleep deprivation or disruption among these workers can have serious consequences as has been observed in several catastrophic incidents and accidents (Horne & Reyner, 1995). For example, fatigue has been found to play a contributory role, in addition to various additional factors, in well-known serious industrial events such as the Chernobyl (1986) and Three Mile Island (1979) nuclear power plant explosions, when the Exxon Valdez ran aground (1989), the Challenger space shuttle crash (1986) and the running aground of the Shen Neng on the Great Barrier Reef (2010) (Reason, 1990). Any industry which operates 24 hour activities is highly susceptible to human error as a result of sleep deprivation (Moore-Ede, 2003) such as the nursing, medical, mining, maritime, and transport industries.

One industry which has received relatively limited attention, despite the high risks at stake, is the commercial aviation industry. Commercial airline pilots are subjected to highly demanding, complex and stressful work environments, long duty periods and disrupted circadian rhythms as a result of round-the-clock operations – all key factors which contribute to operator fatigue (Sadeghniiat-Haghighi & Yazdi, 2015). Furthermore, sleep disruption and fatigue are proposed to be rife among the commercial pilot population with a 2012 survey conducted by the European Cockpit Association stating that over 50% of pilots reported experiencing fatigue levels which they found to impair their abilities while on duty (ECA, 2012). Loss of sleep and fatigue are proposed as major causes of pilot error (Helmreich, 2000). Furthermore, pilot fatigue has been on the U.S. National Transport Safety Board's Most Wanted Transportation Safety Improvements list since its inception in 1990 (NTSB, 1990). From a flying performance perspective, as fatigue increases, accuracy and timing decline, attention narrows, reductions in performance are accepted and pilots abilities to integrate information from individual flight instruments into a significant overall pattern decreases (Caldwell & Caldwell, 2003). Lapses or disregard for vital aspects of flight tasks ensue and reductions in ability to efficiently time-share mental resources occur. Following 20 – 24 hours continuous wakefulness, pilots' control of even basic flight parameters has been shown to significantly deteriorate (Previc et al., 2009). As a result, it is imperative to better predict when operators are likely to experience fatigued-based reductions in performance utilising valid and reliable psychological and/or cognitive tests which are quick and easy-to-administer (Lopez et al., 2012).

A variety of studies have demonstrated significant reductions in performance on basic cognitive tasks in sleep deprived and fatigued individuals (Caldwell et al., 2003; Dinges et al., 1997). According to Lopez et al., (2009) use of such tasks hold great promise as potential predictors of declining performance among sleep deprived and fatigued individuals in real-world tasks such as driving long-haul trucks or flying an airplane. Nevertheless, the degree to which simple cognitive tasks can be utilised to predict reductions in performance in 'real-world' tasks remains unclear, warranting further investigation. Prior research has found that physiological measures acquired from eye-tracking and electroencephalogram (EEG) tests are often difficult and expensive to implement in real-world environments. Furthermore, these measures do not appear to reliably predict sleep deprived and fatigued-related impairments or performance on criterion tasks (Caldwell et al., 2004). Even with greater reliability and validity, these measures still have little connection between the theoretical constructs underlying those assessments and errors in real-world tasks.

According to the International Civil Aviation Organisation's (ICAO) manual of evidence-based training, problem solving and decision-making is a key construct required by pilots for safe and effective flight (ICAO Manual, 2013). Pilots are often required to innovatively respond to unique challenges, novel task demands and make timely and correct decisions in chaotic situations (Adams, 1993), without which the outcome could have catastrophic effects. Furthermore, during flight, pilots are required to conduct numerous tasks concurrently. For example, pilots must manage the status of the aircraft system and anticipate future tasks as well as conduct their primary tasks such as flying, navigation and communications (Lee, 2010). There may be reason to believe that problem solving and multi-tasking may correlate well with flight performance during sleep deprivation and fatigue. Solving mathematical calculations has been employed in previous sleep deprivation and fatigue research have been found to indicate declines in problem solving performance with increasing time awake (Kaliyaperumal et al., 2017; Thomas et al., 2000). Furthermore, divergent tasks such as multi-tasking and flexible thinking have consistently been found to be susceptible to loss of sleep and fatigue (Goel et al., 2009). General cognitive ability is considered the greatest predictor of pilot overall performance (McHenry et al., 1990; Olea & Ree, 1994; Ree, Earles, & Teachout, 1994). Additionally, fluid intelligence is associated with the prefrontal cortex, as are executive functions, of which include divergent thinking and creativity and are particularly vulnerable to sleep deprivation (Crisp & Meleady, 2012; Harrison & Horne, 2000). Whether these variables are related to performance under conditions of sleep deprivation and fatigue are yet to be determined.

Maintaining awareness of the work environment, comprehending the information it holds and predicting how the situation will develop are some of the critical factors in the prevention of industrial accidents (Jones & Endsley, 2000; Stanton et al., 2001). Situation awareness is another of the core competencies identified by the ICAO are essential for safe and effective flight (ICAO Manual, 2013). Pilots need to have an awareness of the aircraft state in its environment and be able to project and anticipate changes (ICAO Manual, 2013). It is considered a critical criterion for the safe and effective operation of complex dynamic systems such as an aircraft (Sarter & Woods, 1991). Situational awareness has consistently been found to be susceptible to sleep deprivation and fatigue (Caldwell et al., 2004; Endsley, 1999; Sexton et al., 2000; Tucker et al., 2010). Not only does situational awareness fall under the realm of executive functions which are associated with the prefrontal regions of the brain (Thomas et al., 2000), loss of situational awareness manifests itself in the operator as the failure to continue responding appropriately or even in responding to the situation completely inappropriately. Furthermore, decreased situational awareness has been referred to as a causal factor in several aviation mishaps (Taylor, 1990). It is therefore proposed that situational awareness may also have the ability to predict flight performance changes.

Sleep deprivation and fatigue has been widely tested in the aviation industry using the Psychomotor Vigilance Task (PVT) developed by Dinges and Powell (1985) (see also Lim & Dinges, 2010). PVT performance has been shown to consistently decline with reduced sleep (Dinges et al., 1997; Russo et al., 2005). However, despite being considered the ‘gold standard’ for measuring fatigue in an aviation context, much remains unknown about the task and what it measures with a paucity of findings highlighting its relationship with real-world tasks. Several psychological tasks may have promise, including the Profile of Mood States (POMS) (McNair et al., 1971) questionnaire, a psychological rating scale used to evaluate transient, distinct mood states. This measure has been proven to be valid among healthy adult populations, has a high internal consistency and is sensitive to fatigue (Terry, Lane & Fogarty, 2003). Further, POMS may have the ability to aid in the prediction of flight performance changes since Previc et al. (2009) found flying errors following 24 – 28 hours continuous wakefulness peaked in line with peaks in subjective fatigue, determined by the POMS.

The present research aimed to investigate if analogue measures of key competencies required by commercial airline pilots to successfully operate an aircraft may aid in predicting sleep deprived or fatigued-related performance decrements on a computerised flying simulator task. The overall purpose of this study was to (i) investigate overall changes in performance in sleep deprived commercial airline pilots, and (ii) compare different psychological measures and cognitive tests as potential predictors of flight performance over a period of continuous wakefulness. Sleep deprivation and fatigue pose an insidious threat to flight safety. Enhancing our understanding of sleep deprivation and fatigue in the aviation domain would aid in accident prevention and promote safety.

6.2.3 Methods

6.2.3.1 Participants

Five male and two female commercial airline pilots (age 35 ± 5.72 years, height 177.65 ± 10.31cm, body mass 78.00 ± 12.62kg) were recruited to partake in this study. All participants were active-duty short-haul commercial airline pilots with an average of 4,950 hours flying experience. Prior to any data collection, ethical approval was granted by Dublin City University Ethical Committee (Appendix C). All participants provided written consent prior to participation (Appendix I & J).

No participant had previously engaged in sleep deprivation studies or reported sleep disorders as determined by the SLEEP-50 questionnaire (Spoormaker et al., 2005) and all had normal vestibular function as assessed by the Sharpened Romberg Test. Furthermore, no pilot suffered from vestibular symptoms such as dizziness, vertigo, and disorientation or reported sleep problems or seizures. All were non-smokers and none were presently taking any form of medication known to impact mental alertness (i.e. sleep medications, prescription stimulants, sedating antihistamines, etc.). All participants completed a food, activity and sleep log and wore a wrist- sleep and activity monitor (Fitbit Charge FB404BKL, Fitbit Inc.) for the 4 days prior to each testing period. Participants recorded an average of 7hrs 59min sleep (ranging from 6hrs 37min to 9hrs 46min) in the three nights prior to baseline testing. Participants also refrained from alcohol and vigorous exercise for the 24 hours prior to each testing period.

6.2.3.2 Testing Apparatus

This study was conducted in the laboratories of the School of Health & Human Performance in Dublin City University. Flight performance measurements were collected on a computerised flight simulator (AIRSIM). The remaining measures were collected via pen-and-paper, desktop computers and laboratory testing devices set up in a designated testing room in the laboratory.

Psychological Measures

- Profile of Mood States-30

The Profile of Mood States-30 questionnaire (POMS-30) (McNair et al., 1971) is a 30-item measure of mood state. This measure consists of six different mood states subscales: Tension, Depression, Anger, Vigour, Fatigue and Confusion. A seventh score – Total Mood Disturbance (TMD) – was also calculated by subtracting the score of the one positively scored subscale, vigour, from the sum of the other five subscales.

- Samn-Perelli Crew Status Check

The Samn-Perelli Crew Status Check (SPC) (Samn & Perelli, 1982) is a 7-item measure of fatigue. It was initially developed for military airlift operations and has been widely used in aviation studies (Samel et al., 1997). The ratings are consistent with the ICAO definition of fatigue and are explicitly linked to the likelihood of performance impairment.

Cognitive Measures

- Psychomotor Vigilance Task

The Psychomotor Vigilance Task (PVT) is a 10-minute visual psychomotor task which was conducted on the PC-PVT v1.1.0. It has been shown to compare favourably to the gold standard PVT-192 device (Khitrov et al., 2014). Participants were required to respond to a visual stimulus presented on the screen by clicking on the high USB poll rate mouse button (Logitech M325). Stimuli appeared at random intervals varying from 2 – 10 seconds. Mean reaction time (PVT-MRT) was recorded along with lapses in attention (a response time of >500ms) (PVT-MLA).

- Dual-N-Back Task

Multi-tasking ability was assessed via the Dual-N-Back test (Jaeggi et al., 2010) using the Inquisit 4 [Computer software]. During this task participants are presented with two sequences of stimuli in two modalities at the same time (i) a visual stimulus and (ii) an auditory stimulus. In each trial one visual and one auditory stimulus are presented and participants are asked to respond based on whether the visual or auditory stimulus matches that presented n-back. N-backs can range from a 0-back through to a 4-back. Successful Visual Hits (VH) and Auditory Hits (AH) were recorded.

- Rapid Visual Information Processing Task

The Rapid Visual Information Processing Task (RVP) is a measure of sustained attention and forms part of the Cambridge Neuropsychological Test Automated Battery (CANTAB). During this task, a white box is displayed in the middle of the screen, inside which digits ranging from 2 to 9 appear in a pseudo-random order, at a rate of 100 digits per minute. Participants are required to detect target sequences of digits (e.g. 2-4-6; 3-5-7; 4-6-8). Level of difficulty varies with either one- or three-target sequences that the participant must watch for at the same time. Number of correct rejections and missed sequences were recorded.

- Mathematical Calculations

Aviation-specific mathematical calculations were used as a measure of problem-solving (van Dongen et al., 2003). Three moderate- and three difficult-level mathematical calculations were presented to participants. Time taken (TT-MC) and correct responses (CR-MC) were used as an assay of problem-solving timing and accuracy. Mathematical calculations were obtained from the ‘Compass Test’ (Computerised Pilot Aptitude Screening System) which consists of a set of psycho-motor and psycho-technical tests specific for commercial airline pilot training. These tests are produced by EPST (European Pilot Selection & Training) and are compliant with the standards used by all flight schools and major airlines during pre-hire screening.

Flight Performance

One purpose of this study was to determine which cognitive measures best predict flight performance with increasing time awake. Participants were required to manually fly a 32-minute flight profile on an Avionics Integration Research SIMulator (AIRSIM) (Groeneweg, 1998) (Appendix K). This is a high fidelity, desktop research flight simulator which consisted of an Airbus interface, of which all participants were familiar. The flight profile consisted of three segments (see Figure 6.1 for the flight profile). Flight commenced mid-air (heading 090 degrees, at 10,000ft, travelling at 250 knots) and no take-off or landing were included in the flight profile. Participants were tasked with flying a holding pattern as a result of icy conditions at their destination runway. They were commanded to perform specific control or performance parameters including airspeed, heading, altitude and bank at various time points throughout the flight task. Flight commands and instructions were provided via air traffic controller voice recordings. Participants were also required to conduct mid-flight fuel calculations whilst flying the holding pattern. Time taken (TT-FC) and correct responses (CR-FC) were recorded. Furthermore, participants were required to answer mid-flight situation awareness questions regarding their location, speed, heading, altitude and on static TCAS (Traffic Avoidance Collision System) pictures which were shown for a 5-second period at specific time points during the flight profile. Number of correct responses to situation awareness questions (SA) was recorded. Deviation (horizontal and vertical deviation from the specified flight path – HDEV and VDEV, respectively), speed (total airspeed – TAS), and throttle (average throttle magnitude – ATM), pitch (average pitch magnitude – APM) and roll (average roll magnitude – ARM) input were used as indicators of objective flying performance. Root mean square errors (RMSE) from the specified flight parameters were calculated for each flight task. Overall composite flight performance deviation (FP) RMSE, which consisted of an amalgamation of average horizontal deviation RMSE and average vertical deviation RMSE, was analysed. The National Aeronautics and Space Administration-Task Load Index (NASA-TLX) was used to assess perceived mental workload (Hart & Staveland, 1988) and was administered immediately following the flight task.

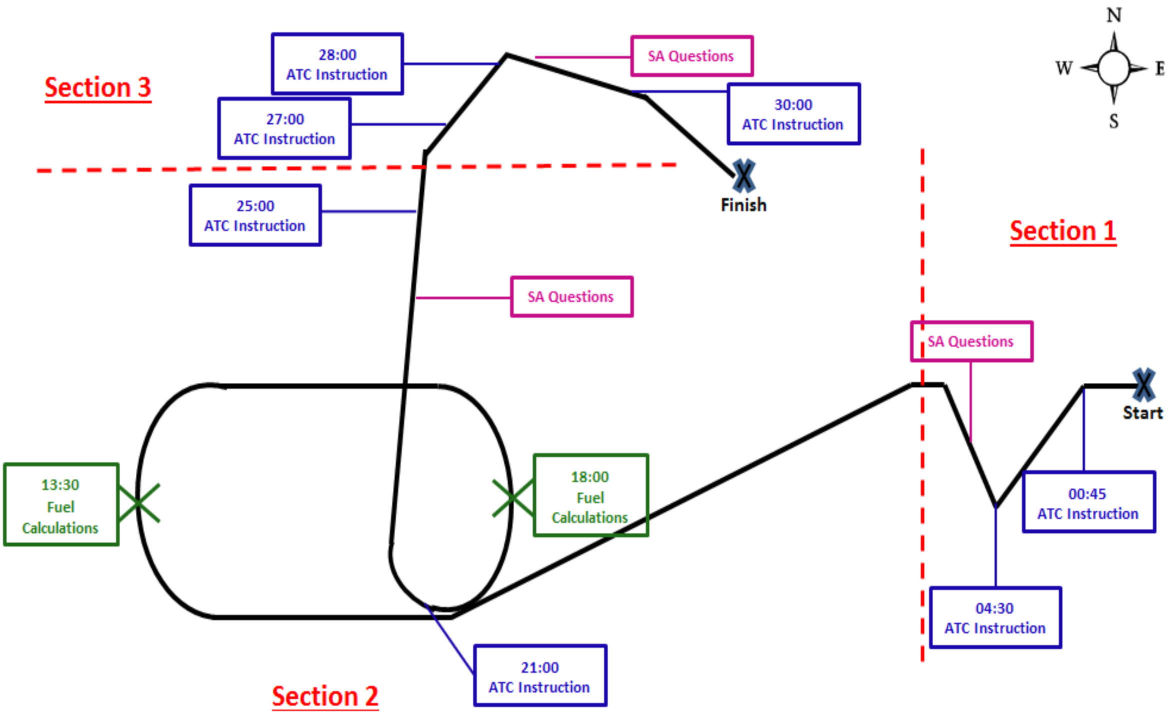

Figure 6.1. Computerised Flight Simulator Flight Profile

6.2.3.3 Procedure

Participants attended the laboratory on three occasions: (1) during the initial visit, participants were familiarised with the experimental tests and procedures with each participant completing three training/familiarisation sessions; (2) during the second visit, participants undertook baseline and twelve-hour testing on the third rest day of an off-duty period and; (3) during the third visit, participants completed the sleep deprivation testing during which each participant completed 5 testing sessions that covered the final 12 hours of a 24 hour period of continuous sleep deprivation following a 5-day 'morning' duty period (see Figure 6.2 for a schematic of the study design).

Before training began, each participant came to the laboratory, signed an informed consent agreement and was briefed on all upcoming study procedures. Each participant then filled out a short biographical/medical history questionnaire and other study paperwork and was screened for sleep disorders and vestibular function. Participants then completed familiarisation testing during which they completed the full battery of all tests.

On the third rest day of a duty period, participants arrived at the laboratory at 0800h, haven awoken at 0600h. They refrained from vigorous exercise and alcohol for the 24 hours prior to baseline testing (BLINE) and aimed to obtain three nights of undisturbed sleep (8 hours per night). BLINE testing was conducted between 0800h and 0945h during which all psychological and cognitive tests were conducted (60-minutes) immediately followed by the flight profile (32-minutes). Once this testing session was completed, each participant returned home where they refrained from caffeine, alcohol and vigorous exercise and were encouraged to relax for the day. That evening at 1800h, participants returned to the laboratory where they performed their 12-hour tests (12HR) which consisted of an identical testing schedule as BLINE. On completion of testing at approximately 1945h, each participant returned home.

On the final day of a 5-day duty period, participants arrived at the laboratory at 1800h immediately following their duty, having awoken at 0600h that morning. They refrained from vigorous exercise and alcohol for the 24 hours prior to testing and were permitted to consume only one cup of coffee during the morning period of their duty that day. Testing session 1 (TS1) was conducted between 1800h and 1945h and replicated that performed during BLINE and 12HR following which participants had a 1.15-hour break. Testing session 2 (TS2) was conducted between 2100h and 2200h and contained the psychological and cognitive 60-minute battery of tests but did not include the flight profile. Testing session 3 (TS3) and testing session 5 (TS5) were performed between 0000h and 0145hr, and 0600hr and 0745hr, respectively, both replicating the BLINE, 12HR and TS1 sessions. Testing session 4 (TS4), conducted between 0300hr and 0445hr, did not contain the flight profile and replicated TS2. Between test bouts participants were allowed to read, watch movies, and interact with laboratory staff to help them stay awake, but no vigorous or mentally stimulating activities (i.e., exercise, puzzles) were permitted. Participants were also provided with all food and beverages during over-night testing. No caffeine or stimulants were permitted or provided during the testing periods.

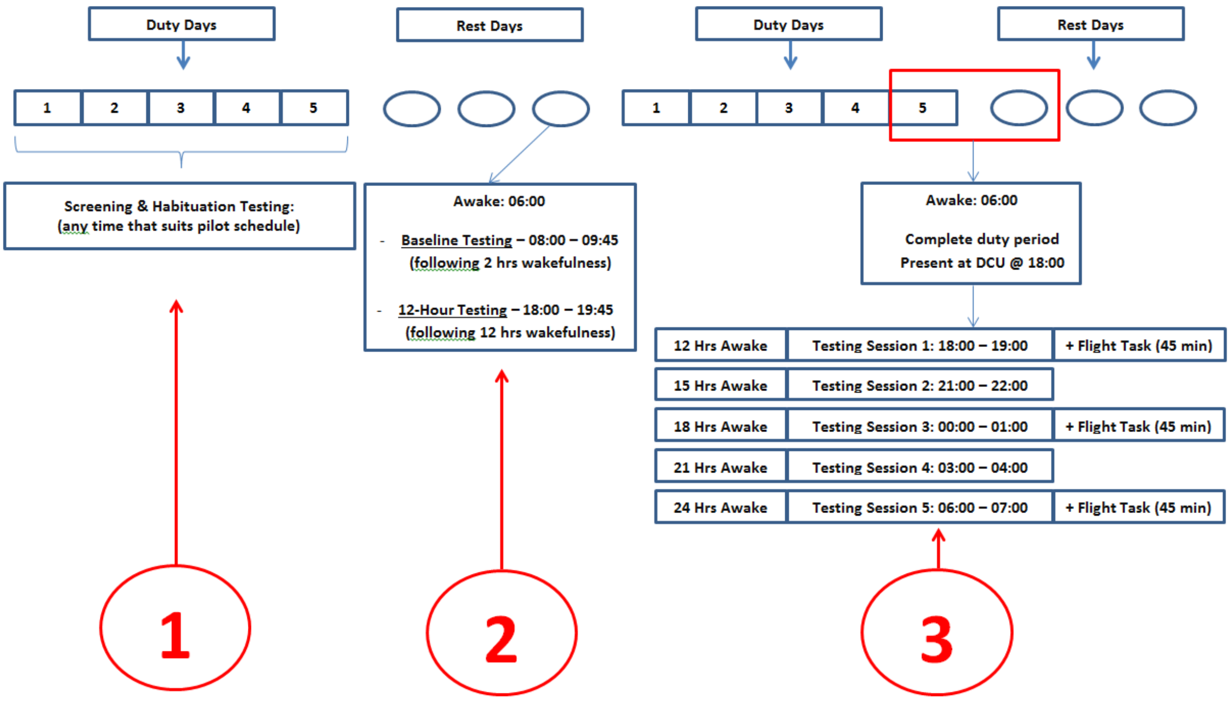

Figure 6.2. Schematic of Study Design

6.2.3.4 Statistical Analysis

All statistical analysis was performed using SPSS Version 23 (SPSS Inc.). Repeated measures analysis of variance (ANOVA) and Friedman tests were performed on the outcome measures for all psychological, cognitive and flight performance tasks to test for changes across the 7 and 5 testing sessions respectively (please see footnotes[9] for non-parametric Friedman Tests

[9] *Due to potential violations of non-normality as a result of a small sample size, Friedman tests were run. Friedman Findings: POMS-Confusion,* $\chi^2(6)=15.904$, $p<.05$; *POMS-Vigour,* $\chi^2(6)=25.564$, $p<.001$; *Total Mood Disturbance,* $\chi^2(6)=27.572$, $p<.001$; *Samn-Perelli Crew Status*

for all repeated measures ANOVA due to small sample size). In instances where Mauchly's test of sphericity was significant, the Greenhouse-Geisser adjusted degrees of freedom were used (denoted by *ƒF* throughout this study). When significance was obtained, post-hoc analysis using a LSD test (following repeated measure ANOVA) and Wilcoxon signed-rank test (following Friedman test) were used to identify where these differences lay. Cohen's *d* was also utilised to demonstrate the size of effect between variables means across testing sessions. An alpha value of $p<0.05$ was used as the criterion for all statistical tests.

To assess individual changes in the effects of sleep deprivation relative to others and the effects of sleep deprivation in a particular individual over time, two sets of correlations were calculated: between-subject and within-subject, respectively. The purpose of computing the between-subject correlations was to determine whether there was a consistent relationship across participants between each cognitive measure and computerised flight simulator performance. To compute the between-subject correlations, the change from the 'rested' state (average of BLINE and 12HR) to the 'fatigued' state (average of TS1 – TS5) was first computed for each participant and measure. Using these changes, a Pearson's product-moment correlation coefficient was calculated for each pairwise combination of outcome measures. The purpose of computing the within-subject correlations was to determine whether, per individual, cognitive changes were related to computerised flight simulator performance changes therefore, do the two variables tend to behave similarly over the 5 testing sessions. The within-subject correlations were calculated as follows: For a given participant and pair of variables (e.g., PVT-MRT and FP), there are 5 pairs of data points representing the 5 sessions that the participant encountered over time. The correlation was calculated from these 5 pairs of points.

The correlations were performed on the relationship between overall flight performance deviation (FP) and: TMD, SPC, PVT-MRT, Multi-Tasking, RVP-Missed, TT-FC, SA, and TT-MC. These measures were chosen as they have been shown to be sensitive measures in prior studies and have shown consistent changes across the 24 hour sleep deprivation period in the present study. This method of statistical analysis replicates that of Lopez et al., in their 2012

Check, $\chi^2(6)=21.868$, $p<.01$; PVT-Minor Lapses in Attention, $\chi^2(6)=25.852$, $p<.001$; PVT-Mean Reaction Time, $\chi^2(6)=29.878$, $p<.001$; Multi-Tasking Ability, $\chi^2(6)=9.810$, $p=.133$; Visual Hits, $\chi^2(6)=9.079$, $p=.169$; Auditory Hits, $\chi^2(6)=7.441$, $p=.282$; RVP-Correct Rejections, $\chi^2(6)=20.406$, $p<.01$; RVP-Misses, $\chi^2(6)=23.207$, $p<.01$; Time Taken for aviation-specific mathematical calculations, $\chi^2(6)=20.082$, $p<.01$; Situation Awareness, $\chi^2(4)=11.496$, $p<.05$; Time Taken for mid-flight fuel calculations, $\chi^2(4)=11.543$, $p<.05$.

study which investigated the effects of sleep deprivation on cognitive performance in Air Force pilots.

6.2.4 Results

6.2.4.1 Psychological Measures Data

Self-reported confusion and vigour both indicated significant changes, $F(6, 36)=5.125$, $p<.05$, and $F(6, 36)=11.465$, $p<.001$, respectively, with confusion generally increasing over time and vigour decreasing over time. Post hoc comparisons indicated that self-reported confusion was significantly increased relative to baseline levels at TS1 (12 hours wakefulness), $p=.058$ ($d=1.15$), continuing until TS5 (24 hours wakefulness), $p=.026$ ($d=1.42$). Additionally, self-reported vigour was significantly decreased relative to baseline levels at TS2 (15 hours wakefulness), $p=.020$ ($d=1.42$), continuing until TS5 (24 hours wakefulness), $p=.004$ ($d=2.68$).

TMD and subjective fatigue, as determined by the SPC, also showed significant changes, ƒ$F(1.756, 10.539)=8.734$, $p<.01$, and $F(6, 36)=6.585$, $p<.001$, respectively, with both generally increasing over time. Post hoc comparisons identified that both TMD (see Figure 6.3) and subjective fatigue significantly increased relative to baseline levels at TS1 (12 hours wakefulness), $p=.039$ ($d=1.31$) and $p=.035$ ($d=1.45$), continuing until TS5 (24 hours wakefulness), $p=.011$ ($d=1.99$) and $p=.002$ ($d=2.59$), respectively, with the exception of TS2 where a brief reduction in both TMD and subjective fatigue was observed.

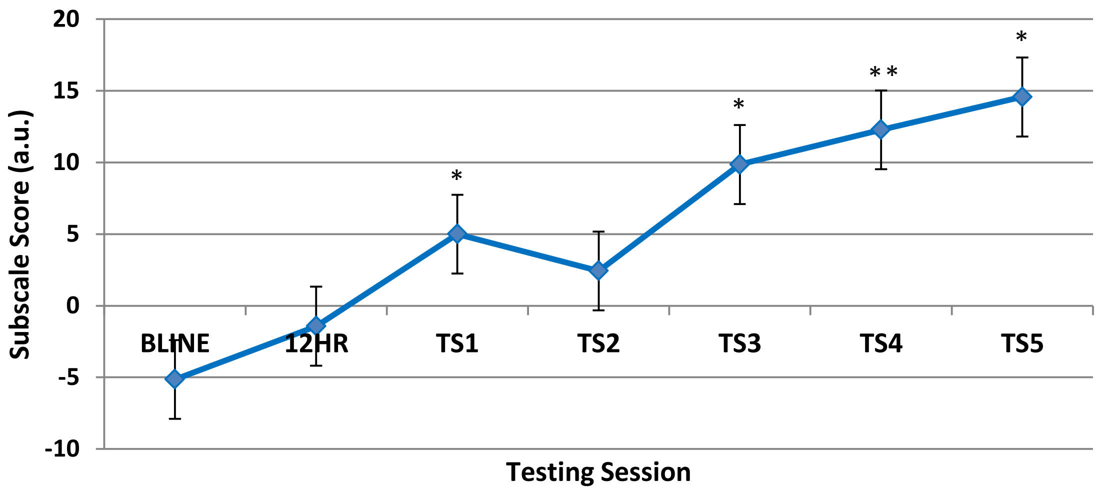

Figure 6.3. Mood – Total Mood Disturbance (±SE) for each of the testing sessions.
*** indicates significant differences from the baseline session (*p*<.05); ** indicates significant differences from the baseline session (*p*<.01)**

The between-subject correlations of the change in TMD with the change in flight performance deviation composite RMSE was moderate, *r*=0.31 whilst the change in SPC and FP was weak, *r*=0.09 (Table 6.1). As regards the within-subject correlations between self-reported TMD and FP, 4 of the 7 within-subject correlations ranged from moderate to strong, *r*=0.30 to 0.93, with three participants showing negative correlations (Table 6.2). The within-subject correlations between subjective fatigue and FP were moderate with 4 of the 7 participants showing negative correlations, *r*=-0.08 to -0.96. These results suggest that psychological measure changes and flight performance changes may not be related.

6.2.4.2 Cognitive Measures Data

Both PVT-MLA and PVT-MRT showed significant changes ƒ*F*(1.643, 9.860)=4.913, *p*<.05 and ƒ*F*(1.193, 7.157)=6.491, *p*<.05, respectively, with both generally increasing over time. Post hoc comparisons revealed both PVT-MLA and PVT-MRT began to significantly differ from baseline levels beginning at TS4 (21 hours wakefulness), *p*=.053 (*d*=1.28), and *p*=.059, respectfully, with reaction time being, on average, 47.69% (*d*=1.05) (TS5 – 24 hours wakefulness) slower than baseline values (see Figure 6.4). The between-subject correlation of the change in PVT-MRT with the change in FP was moderate, *r*=0.32 (Table 6.1). In addition, 3 of the 7 within-subject correlations between PVT-MRT and FP were strong, *r*=0.52 to 0.67, however, three participants showed correlations in the opposing direction (Table 6.2).

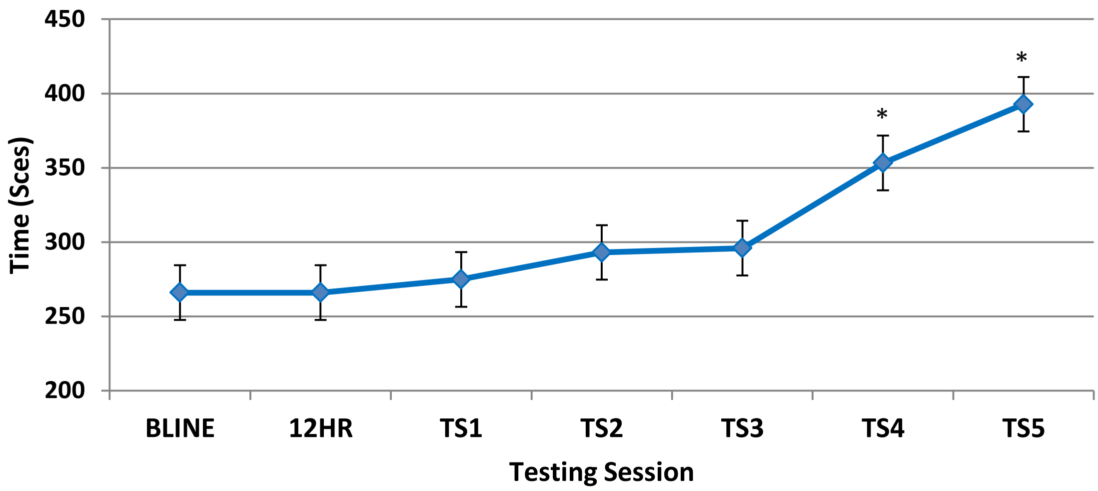

Figure 6.4. Objective Fatigue – PVT-Mean Reaction Time (±SE) for each of the testing sessions.

*** indicates significant differences from the baseline session (*p*<.05)**

Figure 6.5 depicts multi-tasking ability (as measured by the Dual-N-Back) which showed changes, generally decreasing with increasing time awake although no significant differences were found relative to baseline values. This task was sub-divided in to a visual and auditory component. VH showed significant changes over the period of sleep deprivation, $F(6, 36)=3.038$, $p<.05$, somewhat fluctuating over time, whilst AH generally indicated a reduction in performance with increasing time awake, but this was not found to be significant, $F(6, 36)=1.483$, $p=.212$. The between-subject correlations of the change in multi-tasking ability with the change in FP was weak, $r=0.06$ (Table 6.1). Furthermore, the within-subject correlations between multi-tasking ability and FP were moderate to strong for 3 of the 7 participants, $r=-0.28$ to -0.94, but four participants showed correlations that were either weak or in the opposing direction (Table 6.2).

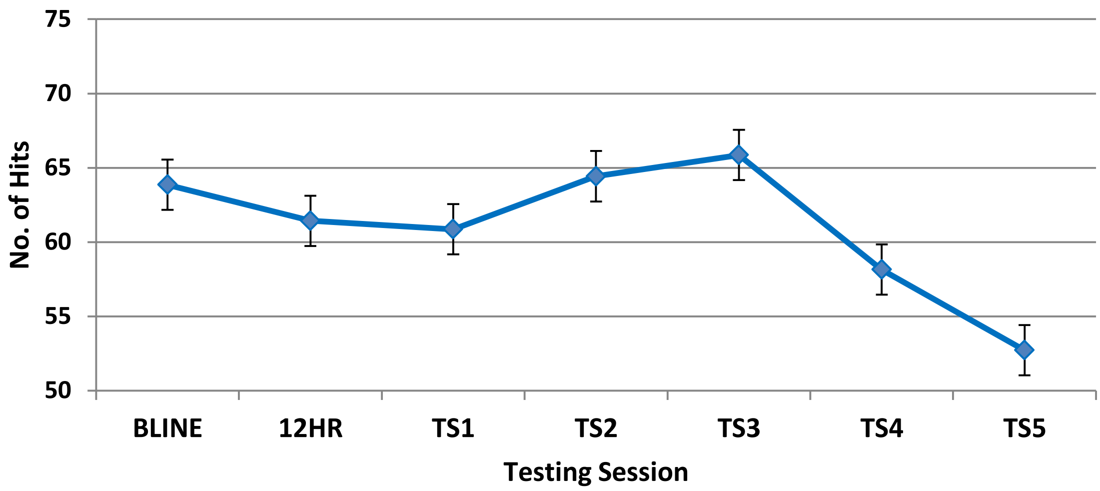

Figure 6.5. Multi-Tasking – Multi-Tasking Ability (combination of Visual Hits & Auditory Hits) (±SE) for each of the testing sessions.

As regards sustained attention, the RVP revealed significantly fewer correct rejections ƒ$F(2.173, 13.041)=10.696$, $p<.01$, and significantly more misses with increasing time awake $F(6, 36)=9.837$, $p<.001$. Post hoc comparisons identified TS4 (21 hours wakefulness) as the point at which performance on this task, $p=.028$ ($d=1.02$) and $p=.028$ ($d=1.09$), respectively, became significantly impaired relative to resting values (i.e. 12-HR) (see Figure 6.6). The between-subject correlation of the change in missed sequences with the change in FP was weak, $r=0.08$ (Table 6.1). The within-subject correlations showed weak to strong correlations for 4 of the 7 participants, but three participants showed correlations in the opposite direction, $r=-0.13$ to -0.85, (i.e., a negative relationship was identified) (Table 6.2). These results suggest that changes in sustained attention, as determined by the RVP, and flight performance changes may not be related.

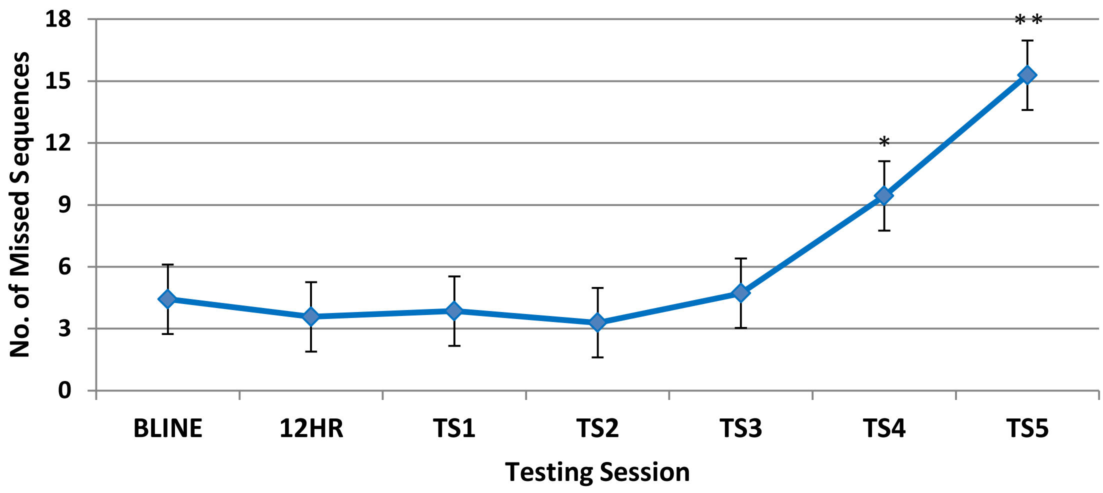

Figure 6.6. Sustained Attention – RVP-Missed Sequences (±SE) for each of the testing sessions.

*** indicates significant differences from the 12HR session (*p*<.05); ** indicates significant differences from the 12HR session (*p*<.01)**

TT-MC showed significant changes $F(6, 36)=5.897$, $p<.001$, generally increasing over time whilst CR-MC generally decreased over time $\chi^2(6)=20.463$, $p<.01$. Post hoc analysis indicated TS3 (18 hours wakefulness) as the point at which TT-MC, $p=.056$, became significantly impaired taking, on average, 43.92% ($d=1.23$) longer relative to baseline values as can be seen in Figure 6.7. CR-MC significantly differed from baseline values at TS2 (15 hours wakefulness), $p=.034$ ($d=1.31$), and TS3 (18 hours wakefulness), $p=.034$ ($d=1.09$), following which an improvement in performance was observed, particularly in TS5 (24 hours awake). The between-subject correlation of the change in TT-MC with the change in FP was weak and in the opposite direction, $r=-0.14$ (Table 6.1). In addition, the within-subject correlations between TT-MC and FP were moderate to strong, $r=0.23$ to 0.91, however, 3 of the 7 participants either demonstrated correlations that were weak or in the opposite direction (Table 6.2).

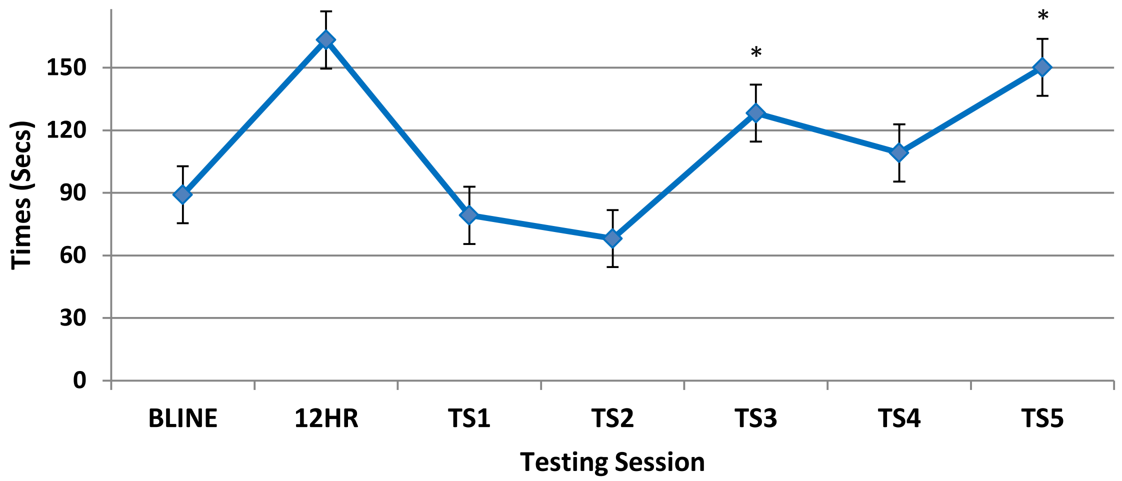

Figure 6.7. Problem Solving – Time Taken to complete Mathematical Calculations (±SE) for each of the testing sessions.

*** indicates significant differences from the baseline session (*p*<.05)**

Perceived workload, as determined by the NASA-TLX, showed significant changes over time, $F(4, 24)=2.740$, $p<.05$, significantly differing from baseline levels at FT2 (18 hours wakefulness), $p=.043$ and continuing until FT3 (24 hours wakefulness), $p=.047$. Perceived workload values were, on average, 11.95% ($d=.75$) and 11.19% ($d=.90$) higher at FT2 (18 hours wakefulness) and FT3 (24 hours wakefulness) relative to baseline values, respectively.

Table 6.1. Between-subject flight performance deviation correlations with (95% confidence limits).

	Changes in Flight Performance Deviation
TMD	0.31 (-0.57, 0.86)
SPC	0.09 (-0.71, 0.78)
PVT-MRT	0.32 (-0.57, 0.86)
Multi-Tasking	0.06 (-0.72, 0.77)
RVP-Missed	0.08 (-0.71, 0.78)
TT-MC	-0.14 (-0.80, 0.68)
SA	-0.47 (-0.90, 0.43)
TT-FC	0.62 (-0.24, 0.93)

Note: TMD, Total Mood Disturbance; SPC, Samn-Perelli Crew Status Check; PVT-MRT, Psychomotor Vigilance Task-Mean Reaction Time; Multi-Tasking, Multi-Tasking Ability; RVP-Missed, Rapid Visual Information Processing Task-Missed Sequences; TT-MC, Time Taken-aviation-specific mathematical calculations; SA, Situation Awareness; TT-FC, Time Taken-mid-flight fuel calculations.

Table 6.2. Within-subject flight performance deviation correlations.

	TMD – FP	SPC – FP	PVT-MRT – FP	Multi-Tasking – FP	RVP-Missed – FP	TT-MC – FP	SA – FP	TT-FC – FP
P1	-0.73	-0.63	-0.35	-0.28	0.23	0.24	-0.48	0.10
P2	-0.96**	-0.96**	-0.94*	0.73	-0.77	-0.31	-0.37	-0.64
P3	0.55	-0.08	0.16	0.68	-0.13	0.47	-0.20	-0.01
P4	0.30	0.36	0.56	-0.77	0.70	0.01	-0.37	0.80
P5	-0.80	-0.76	-0.73	0.18	-0.85	0.23	-0.48	-0.66
P6	0.66	0.52	0.52	-0.94*	0.76	0.91*	-0.17	0.67
P7	0.93**	0.45	0.67	-0.19	0.03	-0.31	-0.31	0.32

Note: TMD, Total Mood Disturbance; SPC, Samn-Perelli Crew Status Check; PVT-MRT, Psychomotor Vigilance Task-Mean Reaction Time; Multi-Tasking, Multi-Tasking Ability; RVP-Missed, Rapid Visual Information Processing Task-Missed Sequences; TT-MC, Time Taken-aviation-specific mathematical calculations; SA, Situation Awareness; TT-FC, Time Taken-mid-flight fuel calculations.

* Significant at $p<.05$; ** Significant at $p<.01$

6.2.4.3 Flight Performance Data

SA showed significant changes over the sleep deprivation period, $F(4, 24)=2.923$, $p<.05$, somewhat fluctuating but generally decreasing over time. Post hoc comparisons revealed that SA significantly differed from baseline levels at FT3 (24 hours wakefulness), $p=.004$ ($d=1.16$), decreasing, on average, by 18.93% (see Figure 6.8). The between-subject correlation of the change SA with the change in FP was moderate, $r=-0.47$ (Table 6.1). In addition, the within-subject correlations between SA and FP were weak to moderate with all 7 in the same direction (Table 6.2). These results suggest that in this particular study, changes in SA appear to be most closely related to changes in flight performance.

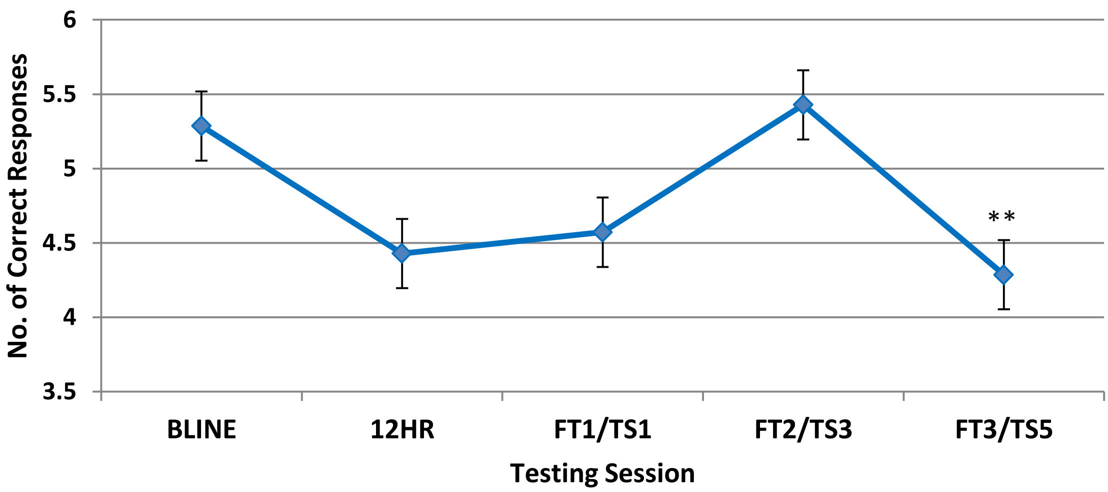

Figure 6.8. Situation Awareness – Situation Awareness (±SE) for each of the testing sessions. ** indicates significant differences from the baseline session (*p*<.01)

TT-FC showed significant changes $F(4, 24)=8.561$, $p<.001$, maintaining relatively stable until FT2 (18 hours wakefulness) whilst CR-FC did not significantly differ with increasing time awake $\chi^2(4)=2.667$, $p=.615$. Post hoc analysis Identified FT3 (24 hours wakefulness) as the point at which time taken, $p=.002$, became significantly impaired taking, on average, 74.0% ($d=1.24$) longer relative to baseline values (see Figure 6.9). The between-subject correlation of the change in TT-FC with the change in FP was strong, $r=0.62$ (Table 6.1). Also, 3 of the 7 within-subject correlations were moderate to strong, $r=0.32$ to $r=0.80$, but four participants did show correlations that were weak or in the opposing direction (Table 6.2).

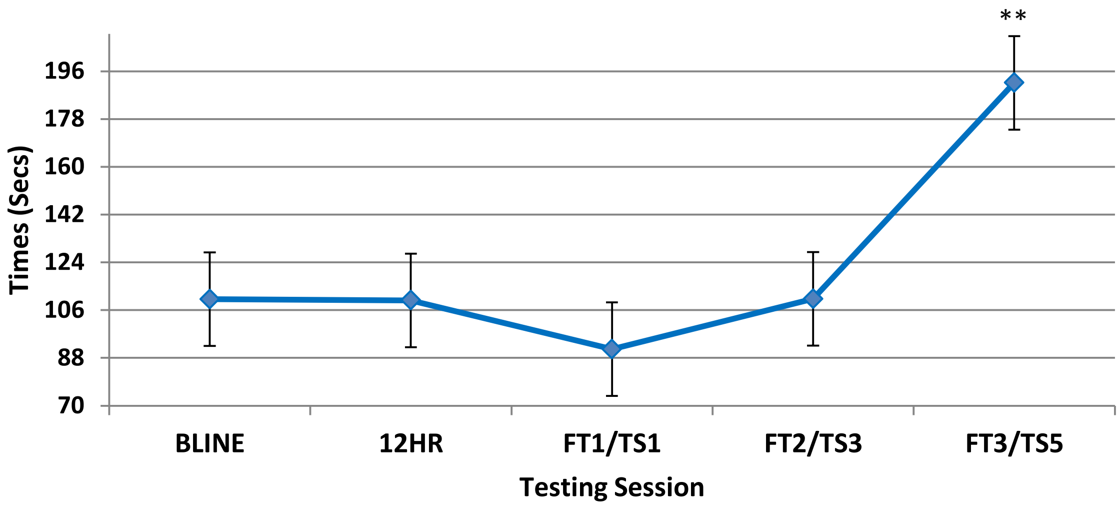

Figure 6.9. Problem Solving – Time Taken to complete Mid-Flight Fuel Calculations (±SE) for each of the testing sessions.

**** indicates significant differences from the baseline session (*p*<.01)**

As regards objective flying performance, TAS appeared to decrease over time F(4,24)=1.311, *p*=.294, but this was not found to be significant. However, the number of times speed was ±10 knots from the specified speed was found to significantly change over time, F(4,24)=42.120, *p*=.000. Post hoc comparisons revealed that there was a significant increase in the number of times speed was ±10 knots from the specified speed between resting levels (i.e. 12-HR) and FT3 (24 hours wakefulness), *p*=.039 (*d*=.31). ATM did not show significant changes over time, *ƒF*(1.211, 7.264)=.710, *p*=.454, although it did indicate trending increases in magnitude of throttle input with increasing time awake. ATM values were, on average, 2.18% (*d*=.24) and 3.05% *(d*=.39) higher at FT2 (18 hours wakefulness) and FT3 (24 hours wakefulness) relative to FT1 (12 hours wakefulness), respectively. Furthermore, APM did not indicate significant changes over time, *F*(4, 24)=.891, *p*=.484, whilst ARM indicated significant reductions in magnitude of roll input with increasing time awake, *F*(4, 24)=4.206, *p*=<.01.

There were no significant changes in deviation, horizontal or vertical, from the flight path over time, *ƒF*(1.324, 7.947)=.734, *p*=.455, and *F*(4, 24)=1.426, *p*=.256, respectively (see Figure 6.10). As regards HDEV, although a slight improvements in performance was observed in (FT2 – 18 hours wakefulness), performance did decrease in FT3 (24 hours wakefulness) where there was, on average, a 46.36% *(d*=.31) increase in horizontal deviation relative to baseline values. Furthermore, although not significant, average number of points greater than 10 horizontal nautical miles from the specified path was, on average, 50.90% (*d*=.47) (FT1 – 12 hours wakefulness), 63.91% (*d*=.32) (FT2 – 18 hours wakefulness) and 123.30% *(d*=.68) (FT3 – 24 hours wakefulness) higher than resting values (i.e. 12-HR). Furthermore, again although not significant, time spent outside 10 horizontal nautical miles was, on average, 54.53% (*d*=.51) (FT1 – 12 hours wakefulness), 35.84% (*d*=.22) (FT2 – 18 hours wakefulness) and 120.26% *(d*=.66) (FT3 – 24 hours wakefulness), greater than resting values (i.e. 12-HR) indicating trending increases in horizontal deviation from the specified path with increasing time awake. Conversely, number of points outside 10 vertical nautical miles from the specified path appeared to decrease with increasing time awake with an average of a 23.04% (*d*=8.79) (FT1 – 12 hours wakefulness), 16.69% (*d*=1.76) (FT2 – 18 hours wakefulness) and 20.84% *(d*=4.75) (FT3 – 24 hours wakefulness) reduction in number of points outside 10 vertical nautical miles relative to baseline values.

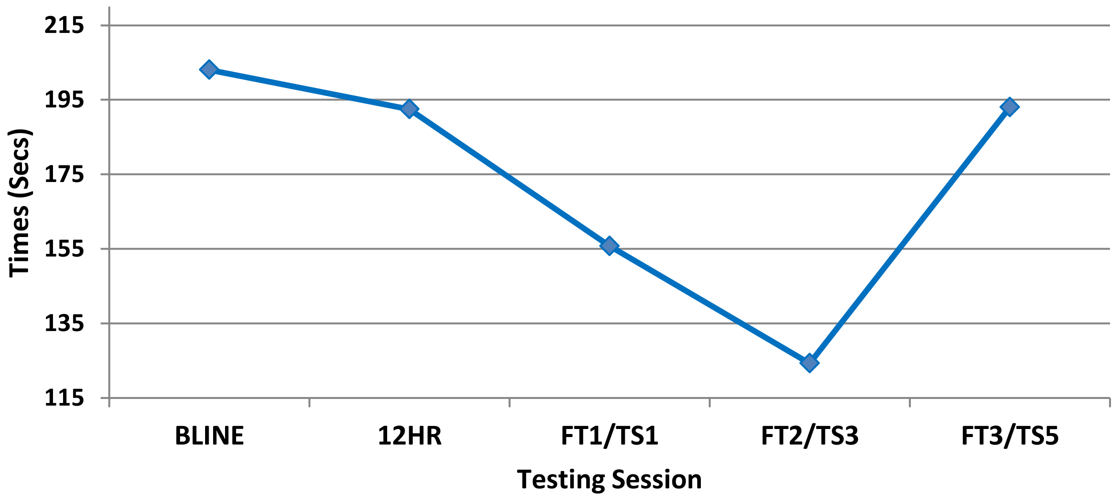

Figure 6.10. Flight Performance – Overall Composite Flight Performance (FP) Deviation RMSE (±SE) for each of the testing sessions.

Table 6.3 contains a summary of the findings for changes in psychological measures and cognitive tasks with increasing time awake.

Table 6.3. Summary of Psychological and Cognitive Repeated Measure ANOVA Findings

Measure	BLINE	12HR	TS1	TS2	TS3	TS4	TS5
Self-Reported Confusion			*	*	*	*	*
Self-Reported Vigour				*	**	**	**
Samn-Perelli Crew Status Check			*		*	**	**
Total Mood Disturbance			*		*	**	*
PVT-Mean Reaction Time	**x**					*	*
PVT-Minor Lapses in Attention	**x**					*	*
Multi-Tasking Ability							
Visual Hits	**x**				*		
Auditory Hits							
RVP-Correct Responses	**x**					*	**
RVP-Missed Sequences	**x**					*	**
Time Taken-Mathematical Calculations					*		*
Correct Response-Mathematical Calculation				*	*		
Situation Awareness							**
Time Taken-Fuel Calculations							**
Correct Responses-Fuel Calculations							
Perceived Workload					*		*

* indicates significant differences from the baseline session (p<.05); ** indicates significant differences from the baseline session (p<.01); X indicates significant differences from resting (i.e., 12HR) session (p<.05)

6.2.5 Discussion

This study aimed to investigate the impact of sleep deprivation and fatigue on measures of psychological and cognitive function: mood (POMS-30), fatigue (SPC), vigilance (PVT), multi-tasking ability (Dual-N-Back), sustained attention (RVP), problem solving (aviation-specific mathematical calculations; mid-flight fuel calculations), and situation awareness (SA) as well as computerised flight simulator performance. Commercial airline pilots were measured on a series of psychological and cognitive tasks over 24 hours sustained sleep deprivation with each test being evaluated on its ability to predict changes in computerised flight simulator performance.

All psychological measures significantly changed with increasing time awake. In all instances, the psychological measures (i.e., mood and subjective measures of fatigue) appeared to begin to decline earlier than performance on cognitive tasks (i.e., objective fatigue, multi-tasking ability, sustained attention etc.) with significant differences been observed at TS1 (12 hours wakefulness) relative to baseline values. These decrements lasted for the entire study. According to Pilcher & Huffcutt (1996), sleep deprivation has a more substantial effect on feelings of fatigue and mood states than on cognitive performance. Changes in psychological measures were not found to be a good predictor of changes in flight performance, despite the SPC being consistent with the ICAO definition of fatigue and its ratings proposed to be linked explicitly to the likelihood of performance impairment (Samn & Perelli, 1982). It is believe a larger sample size would aid in clarifying these results.

Performance on the PVT significantly declined throughout the study with response times being nearly 48% slower following 24 hours continuous wakefulness. These results confirm previous findings that the PVT is a sensitive and reliable test for measuring cognitive decrements during sustained sleep deprivation (Dinges et al., 1997; Russo et al., 2005). The PVT was not found to be highly correlated (either between- or within-subject) with changes in PVT-MRT and flight performance RMSE. This is in contrast with previous finding where Lopez et al., (2012) found good correlations between changes in PVT-MRT and flight performance RMSE with reductions in flight performance beginning to occur at the same time. On closer inspection, it was found that pilots with <5,000 hours flying experience (P2, P3, and P5) may have reacted differently during the period of sleep deprivation than those with >5,000 hours flying experience (P1[10], P4, P6, and P7) in the present study potentially suggesting flight experience may be a determining factor in flying performance during a period of continuous wakefulness. It was found that P2 and P5 appear to improve flight performance whilst P3 also had some more minor improvements in flying performance, thus explaining the inconsistent results in Table 6.2.

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[10] Whilst P1 reported the fewest flying hours, this participant originated from a large aviation background and amassed hundreds of hours flying experience of which do not contribute to his official flying hours experience as a commercial airline pilot. The results suggest P1 reacted in a manner more in line with those with >5,000 hours flying experience on several of the variables.

This is a very unexpected and interesting finding. One potential explanation may be due to the duration of the flight task. This study was performed in a controlled clinical laboratory environment however, the flight task only lasted 32-minutes, to facilitate repeat testing bouts, reduce the benefits of learning effects, and was only performed three times during the period of sleep deprivation. Not only was this task shorter than the combined battery of psychological and cognitive tests (i.e., 60-minutes), it was also considerably more interesting and relevant for participants, potentially more so for those with less flying experience (and who may have felt they had more to prove in a highly competitive and zealous industry), meaning participants may have been able to temporarily increase their effort and thus maintain, and in this instance, improve performance. Furthermore, the prevalent view in the sleep deprivation literature is that high level complex skills (i.e., manually operating a computerised flight simulator) remain relatively unaffected by sleep deprivation due to the interest and inherent encouragement they generate resulting in participants applying compensatory effort to overcome sleepiness (Harrison & Horne, 2000).

As regards multi-tasking ability, both visual and auditory performance decreased with increasing time awake, but only the visual component was significantly impacted. These findings echo that of Jung et al., (2011), who found that sleep deprived individuals were four times more likely to fail to respond to visual stimuli within 10 seconds relative to auditory stimuli. Furthermore, sustained attention, as determined by the RVP, was also significantly impacted by sleep deprivation following 21 hours of continuous wakefulness. Sleep loss consistently demonstrates impairments in sustained attention. This is proposed to occur potentially as a result of the 'state instability' hypothesis such that performance becomes increasingly difficult to maintain stable due to the influence of sleep initiating mechanisms on the endogenous capacity to sustain attention and alertness (Doran, van Dongen & Dinges, 2001). In the current study, changes in multi-tasking ability and sustained attention were not good predictors of flight performance across pilots. As a result of the small sample size, it cannot be firmly concluded that there is no relationship between changes in these variables and changes in flight performance however, these results suggest there may be some promise.

Aviation-specific mathematical calculations were significantly affected by sleep deprivation both in terms of accuracy and speed with significant impairments in performance arising following 15 hours continuous wakefulness. In practice, using attentional focus, individuals are able to switch emphasis between speed and accuracy. However, it has been found that concentrating on improving one aspect of performance can result in the deterioration of the other (Rinkenauer et al., 2004). In self-paced tasks, such as the one employed in this study, there is likely to be a stronger negative impact on speed whilst accuracy remains intact during period of sleep deprivation (DeGennaro et al., 2001). However, numerous studies have shown detrimental effects on both speed and accuracy (i.e., Chee & Choo, 2004; Choo et al., 2005). Time taken to compute the mid-fuel calculations began to significantly increase following 24 hours continuous wakefulness, taking on average, 74% longer then baseline levels. However, accuracy on the fuel calculations was not significantly impaired. Perhaps the regular performance of mid-flight fuel calculations in participants' everyday lives suggesting it is a highly trained skill had an influencing impact on this outcome. Both changes in TT-MC and TT-FC showed potential promise as predictors of changes in flight performance. Changes in basic problem solving ability may have the potential to predict changes in flight performance. Further research is strongly warranted in this area.

Performance on the SA task fluctuated somewhat but declined significantly throughout this study. Additionally, changes in SA correlated well with changes in flight performance, with SA decreasing as deviation in flight performance increased. Good correlations (both between- and within-subject) between changes in SA and flight performance RMSE were identified. Not surprisingly, the best performance in the SA task was identified in FT2, emulating that of overall flight performance. According to Russo et al. (2005), in the field of human factors-related aviation research, performance studies which exclusively focus on identifying pilot flight performance degradations identified loss of situational as one of the key potential factors contributing to real-world flight performance decrements. In addition to showing an overall sleep deprivation effect, adequate between-subject correlations and moderate within-subject correlations, SA tasks are task-specific and relevant, in real-time and require no pre-training.

Overall, performance on all the psychological measures and cognitive performance tasks were significantly affected by the period of sleep deprivation, with the exception of multi-tasking ability and correct responses to mid-flight fuel calculations as can be seen in Table 1, however both of these variables did indicate trending declines in performance. Furthermore, TS1 – 12 hours wakefulness (following a normal duty week) appeared as the point at which psychological measures whilst cognitive performance tasks varied from anything between TS3 – 18 hours wakefulness to TS5 – 24 hours wakefulness depending on the task. However, objective measures of flying performance remained relatively unaffected by 24 hours sleep deprivation. Total air speed, magnitude of throttle, magnitude of pitch and magnitude of roll did indicate some flucations and trending increases in performance with increasing time awake however, none were significantly impacted following 24 hours' sleep deprivation. These findings appear to be incongruence to that of Caldwell at al., (2004) who found substantial decrements in objective flight performance data in the ability to maintain headings, altitudes and airspeeds as a result of increased sleep loss. However, the authors did report that the most noticeable degradations occurred following 27 hours wakefulness possibly suggesting the present study may not have been long enough in order to observe such degradations in performance.

6.2.6 Conclusion

A relatively small sample size combined with the high degree of individual variability response may have had an influencing impact on this study. Furthermore, participants were required to undertake a mentally stimulating flying task which may have under-estimated the impact of sleep deprivation and fatigue on flying performance. However, despite this, the observed findings may hold greater potential operational significance than initially assumed. For example, the present study, particularly manual operation of the computerised flight simulator task (i.e., no use of auto-throttle or auto-pilot), is considerably more alerting and mentally stimulating that various working situations which exist in real-world mid-flight commercial aviation suggesting any declines in performance observed in this study may be further exacerbated in a real-world environment. Furthermore, the flight profile employed in this investigation was relatively short durations (i.e., 32-minnutes – to facilitate repeat testing bouts) in comparison to flight operations which occur in the operational environment. Additionally, following each flight task, participants were able to stand up, walk around, converse with others, snack and watch TV. The factors will have undoubtedly enhance subsequent alertness and performance, at least for a while (Caldwell et al., 2004). Unfortunately, the real-world scenarios for short-haul commercial airline pilots are slightly different where pilots can have flights up to 6 hours continuous. As a result, it is highly likely that any degradation in performance observed during this study will be further compounded in real-world operations.

Today's flight operations work on a pressurised 24/7 timetable and as such, so to do pilots. The unrelenting escalation in international long-haul, short-haul, regional and overnight operations will continue to increase these round the clock requirements (Åkerstedt et al., 2003). As a result, sleep loss and fatigue are becoming even more commonplace in the aviation industry. The findings of this study provide an important indication of commercial airline pilot behaviour over 24 hours of continuous wakefulness. Whilst most pilots were able to maintain flying precision during sleep deprivation, it appears they may be doing so by heavily relying on training and flying experience that can overcome large increases in sleep loss and fatigue which considerably degrades cognitive performance (Previc et al., 2009). Alas, the number of serious accidents as a result of operator error in various industries due to sleep loss and fatigue is large and appears to be increasing (Lopez et al., 2012). The early detection of sleep deprived and fatigued operators may aid in mitigating those accidents. Whilst the within-subject correlations in the present study were quite large, those between the SA and FP were at least all in the predicted direction. Further research is required to determine measures of SA as a potential indicator of an impending precarious situation as a result of sleep loss and fatigue with provisional findings suggesting it holds good promise.

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Disclosure Statement

No potential conflict of interest was reported by the authors.

Chapter 7

Overall Discussion

7.1 Overview of the Research

Discussions for each individual study have been provided in the relevant sections. This chapter will evaluate overall research findings in the context of the existing scientific literature, by examining themes common to each study. These 'overall' findings will then be used to form the main conclusions from this work.

This research aimed to examine the influence of sleep deprivation and associated fatigue on incidents in flight and mental health and to investigate its effects on performance in commercial airline pilots. Very high incidences of self-reported sleep disturbance and fatigue were identified among commercial airline pilots and were found to be associated with incidents in flight and feelings of depression and anxiety. Furthermore, 24 hours' sleep deprivation and subsequent fatigue was found to impair mood, pilot-specific competencies and flying performance.

7.1.1 Rates of Sleep Loss and Fatigue in the Cockpit

The initial study (Study 1), a nation-wide survey, which investigated the attitudes and experiences of Irish-registered commercial airline pilots (*n*=954) to fatigue and the current FTL's, found very high incidences of sleep disturbance and feelings of fatigue in the cockpit. More than 1 in every 5 (22%) pilots reported that they often felt too tired or fatigued to be on active duty in the cockpit. These results somewhat replicate those found by the Swedish (SWALPA), Danish (DALPA) and Norwegian (NRK) Pilot Associations. In addition, more than 1 in every 5 (23%) reported that their work as a commercial pilot negatively influenced their ability to adopt normal sleeping patterns several times per week. Furthermore, SWALPA indicated that the current regulations contained in the EU-OPS Subpart Q were a high (44%) or very high (38%) safety risk as they contribute to a lack of proper rest and sleep. These findings are of great concern.

According to current FTL's, pilots are limited to 190 hours of flight duty in any 28 days or 60 hours of flight duty in any 7 consecutive days. Furthermore, pilots are limited to work 100 block hours in any 28 consecutive days or 900 block hours in a calendar year. Block time refers to "*the time between an aeroplane first moving from its parking place for the purpose of taking off until it comes to rest on the designated parking position and all engines or propellers are stopped*' (ECA, 2007, pp. 3). Pilots are only permitted to fly 900 hours per calendar year which equates to 18 hours per week (over a 50-week working year). However, while pilots are limited to these actual flying hours, not all flight duty periods are spent flying. Additional tasks such as pre-flight preparation and checks, turn-arounds, post-flight paperwork as well as delays and ground duties do not contribute to pilot' block hours. As a result, 24% of those surveyed reported spending 36 – 40 hours on duty in a typical week. Over one third (36.7%) reported spending more than 40 hours on duty in a typical week while just under one fifth (19%) reported spending more than 45 hours on duty in a typical week. Furthermore, as identified in the EU-OPS Subpart Q – "*the European Working Time Directive for Mobile Workers in Civil Aviation also states a maximum block hour annual total of 900 hours and a maximum duty hour total of 2000 hours*" – present reports of spending 40 hours on duty in a typical week press this figure to the maximum over a 50-week (year long) period. According to Skinner & Dorrian (2015), spending 45+ hours working per week significantly increases the risk of insufficient sleep. Additionally, several studies have found clear links between long working hours, decreased sleep quality and quantity and increased fatigued (Barnes, Wagnar & Ghumman, 2008; De Milia et al., 2011; De Raeve et al., 2007). Although the current duty hours are presently within the specified weekly regulations, and which airlines are legally obliged to comply with, the current regulations are a set of 'minimum standards' which are not based on any sound scientific evidence and which the Moebus report (2008) found to be in breach of one or more aspects of fatigue. Accordingly, high reported occurrences of fatigue and sleep disruption among European commercial airline pilots is perhaps unsurprising.

7.1.2 Role of Sleep Loss and Fatigue in Incidents in Flight

In Study 1 it was also found that disturbed sleep and feelings of self-reported fatigue were found to play an integral role in the pathway between long duty hours and incidents in flight with those who spent longer hours on duty being more likely to report having an incident in flight. Length of duty period, loss of sleep prior to the start of duty and long durations of wakefulness during the working day are all key factors which contribute to the development of sleep disruption and fatigue in an aviation setting. These factors can determine the background level of fatigue and alertness at any given moment (Åkerstedt et al., 2003).

There is a palpable pattern that longer duty hours and increases in fatigue result in an increased probability of an accident occurring among commercial airline pilots (Goode, 2003). Powell et al., (2007) concluded that increased duty length is associated with increased fatigue. Long duty hours have the potential to increase acute sleep loss, extended periods of wakefulness and/or greater accumulation of time-on-task (Gander et al., 2011). These factors all contribute to increases in fatigue levels, which in turn can comprise flight safety. In the present study (Study 1), of those who reported that their work as a commercial pilot negatively influenced their ability to adopt normal sleeping patterns that allowed proper rest on a regular basis, 98% reported often feeling too tired/fatigue to be on active duty in the cockpit while 95% reported often experiencing micro-sleeps in the cockpit. Furthermore, according to Bourgeois-Bougrine et al., (2003), domestic pilots most frequently blame their fatigue on sleep deprivation and high workload.

As well as weekly, monthly and yearly flight time limitations, there is also a maximum permitted duty/flight duty period on any one day. Current regulations limit this to 13 hours for up to 2 sectors, however, it is influenced by additional factors such as preceding rest, sectors flown and start time of duty/flight duty period and can be extended to 15 hours in certain circumstances. One third (33%) of those who reported operating duties of >10 but ≤12 hours indicated they performed these duties 2 – 3 times in a typical calendar month while over one quarter (27%) of those who reported operating duties of >12 but ≤14 hours indicated they performed these duties once in a typical calendar month. According to the Moebus Report (2008), "*the provision for EU-OPS for the maximum basic FDP of 13 hours (extending up to 15 hours) are not in keeping with the body of scientific evidence*". Furthermore, according to Goode (2003), for duties durating 10 – 12 hours, there is 1.7 times increased risk of an accident than for all duties whilst duties durating 13 hours or more pose a 5.5 times increased risk of an accident. These findings strongly suggest that current regulations need to be further investigated to ensure they are successfully safeguarding against pilot fatigue.

7.1.3 Role of Sleep Loss and Fatigue on Mental Health

Sleep disturbance and fatigue have substantial short-term and long-term consequences not only on pilot safety, but also on pilot health (Steptoe & Bostock, 2011). Much of the previous scientific literature pertaining to sleep loss and fatigue has tended to focus on its impact on workers performance (e.g., Russo et al., 2005). However, as well as impacting performance, sleep plays an integral role in workers mental health and well-being (e.g., Samel, Wegmann, & Vejvoda, 1997). From the extensive survey conducted in Study 2, it was observed that, as well as influencing performance in the cockpit, sleep disturbance and fatigue were found to have an impact on airline pilots' self-reported anxiety and depression. It was found that those who reported spending longer hours on duty were more likely to report feeling depressed or anxious. Furthermore, those who reported sleep disturbances several times per month or per week, resulting from pilots' inability to adopt normal sleeping patterns that promote proper rest due to work schedules, nearly doubled and tripled, respectively, pilots' probability of reporting feelings of depression or anxiety.

Prior research by Harrington et al., (2001) reported indices suggesting adverse effects of both shift work and long working hours on anxiety and depression potentially suggesting commercial airline pilots may be doubly at risk. Similarly, Virtanen and colleagues (2011) examined long working hours as a potential predictor of depressive and anxiety symptoms among middle-aged British civil servants. After a five year follow-up, they concluded that those working more than 55 hours per week predicted subsequent depressive and anxiety symptoms despite been free from depressive and anxiety symptoms at baseline. Furthermore, regularly experiencing insufficient sleep (less than seven hours) has been linked with an increased risk of anxiety and depression (Pilcher & Huffcutt, 1996; Walker & Stickgold, 2006). A large body of research exists highlighting that poor sleep is a key risk factor for a future depressive episode. Baglioni et al., (2011) conducted a meta-analysis of 21 longitudinal epidemiological studies which investigated sleep and depressive symptoms whilst controlling for baseline depression levels. It was concluded that among those with poor sleep and no depression at baseline, had a two-fold risk of developing depression when re-evaluated 1 year or more later (mean 71±96 months), relative to those with no sleep difficulties.

Various studies have confirmed that sleep complaints are regularly found to precede and predict the onset of depression (Buysse et al. 2008; Gregory et al., 2005; Mallon et al., 2000). As opposed to being a symptom, it has been suggested that insufficient sleep may act as a causal factor which sensitises individuals, contributing to the development of depression and exacerbating symptoms (Baglioni et al., 2011; Benca & Peterson 2008; Riemann & Voderholzer 2003). Whilst this may be the case, experimental studies on sleep disruption and its potential influence on the development of depression are not presently possible on humans for obvious ethical reasons. However, experimental studies conducted among laboratory rodents have demonstrated that chronic sleep restriction may progressively result in neurobiological and neuroendocrine alterations which are very similar to what has been reported for depressed patients, for example, alterations in the regulation of the hypothalamic–pituitary–adrenal axis (Meerlo et al., 2002; Novati et al., 2008), impairments in serotonergic signalling (Roman et al., 2005a, 2006), and reductions in hippocampal volume (Novati et al., 2011). Some of these alterations have demonstrated great persistency, even when the animals were permitted unlimited recovery sleep (Roman et al., 2005a). Experimental findings provide strong support for the hypothesis that, in the long term, insufficient sleep may contribute, at least in part, to the symptoms of depression. Furthermore, this relationship can act in a somewhat cyclical manner. Fatigue was found to be both predictive and a consequence of depressive symptoms (Addington et al., 2001) thus suggesting the presence of depressive or anxious feelings can further exacerbate disruptions in sleep.

7.1.4 Impairments in Performance

Study 3 and 4 further investigated the impact of sleep deprivation and associated fatigue on key pilot-specific competencies and flying performance. Overall, it was found that following 24 hours' sleep deprivation, objective fatigue, sustained attention, cognitive flexibility, hand-eye coordination multi-tasking ability, problem-solving, perceived workload and situation awareness were significantly impacted.

Sleep is generally considered a vital process which serves a key role in neuronal recovery, maintenance, and plasticity therefore suggesting that insufficient sleep may have important repercussions for brain function (Meerlo et al., 2015). It is well established that sleep loss is associated with degradations in basic cognitive function such as alertness, reaction time, attention and vigilance (Dinges et al., 1997, Wesensten et al., 2004) as was also evident in the present studies and in the model identified in Study 1. Lapses in attention and fleeting moments of inattentiveness have been considered key reasons for the reduction in cognitive performance during periods of sleep deprivation (Dorrian et al., 2005), and based on the model identified in Study 1, is associated with errors in flight. According to the 'lapse hypothesis' (Dinges & Kribbs, 1991), sleep-deprived individuals experience temporary phases of low arousal during which sleep intrusions and lapses in performance occur. These lapses, which occur as a result of microsleeps, are characterised by very brief periods of sleep-like electro-encephalography (EEG) activity (Priest et al., 2001). Whilst this theory provides some explanation, findings from chronic sleep restriction studies (Dinges et al., 1997) suggest that it fails to account for changes in neurobehavioural functioning which occur over time. According to Doran and colleagues (2001), reductions in performance during sleep deprivation are due to moment-to-moment variability of attention caused due to the interaction of the homeostatic drive for sleep, the circadian drive for wakefulness, and compensatory effort to perform. It was hypothesised that the variability in performance, as a result of an inability to sustain attention, would ultimately transgress across a wide range of cognitive tasks since attention is a key requirement of numerous goal-directed activities and result in impairments (Doran et al., 2001).

In the present study, various other measures such as a cognitive flexibility, multi-tasking ability and problem-solving were also found to be significantly affected following 24 hours' sleep deprivation. Whilst considerable evidence exists suggesting sleep deprivation degrades performance on simple tasks involving alertness and vigilance, the influence of sleep deprivation on higher-order cognitive processes is less clear (Harrison & Horne, 2000; Jones & Harrison, 2001). Complex cognitive processes, such as cognitive flexibility, planning, and mental abstraction, fall under executive functions (Jones & Harrison, 2001; Lezak, 1995). These executive functions are mainly the result of neural activity within the prefrontal cortex (Roberts, Robbins & Weiskrantz, 1998). According to the 'Neuropsychological Hypothesis', sleep deprivation results in a temporary 'functional lesion' which target the frontal and prefrontal areas of the brain. Supporters of this view construe these findings as a clear indication that impairments observed in complex tasks do not merely occur as a result of the failure of more basic cognitive skills, but that in fact PFC-oriented tasks are vulnerable to specific failures which are above and beyond those expected to occur as a result of low arousal and sleepiness (Harrison et al., 2000).

Objective measures of flying performance remained relatively unaffected by 24 hours' sleep deprivation. Total air speed, magnitude of throttle, magnitude of pitch and magnitude of roll did indicate some fluctuations and trending declines in performance with increasing time awake however, none were significantly impacted following 24 hours' sleep deprivation. These findings appear to be incongruence to that of Caldwell at al., (2004) who found substantial decrements in objective flight performance data in the ability to maintain headings, altitudes and airspeeds as a result of increased sleep loss. However, the authors did report that the most noticeable degradations occurred following 27 hours wakefulness possibly suggesting the present study may not have been long enough in order to observe considerable declines in performance. Whilst most pilots were able to maintain flying precision during sleep deprivation, it appears they may be doing so by heavily relying on training and flying experience that can overcome large increases in sleep loss and fatigue which considerably degrades cognitive performance (Previc et al., 2009). This lends to the suggestion that this may be a regular occurence in Irish cockpits given the high rates of sleep disturbance and fatigue reported in Study 1 relative to the number of incidents and accidents reported. Furthermore, the flying task used in Study 4 was considered a mentally stimulating and interesting task which may have also influenced performance. According to Wilkinson (1992), tasks which are too interesting or complex may intrinsically encourage participants to apply compensatory effort and perform normally and as such these tasks may not be as sensitive to sleep loss. However, this flight task was considered somewhat more exciting and stimulating than the average cockpit mid-flight and yet still demonstrated trending declines in flying performance suggesting that these findings may actually underestimate the impact of sleep loss and fatigue on flying performance.

Interestingly, it was found that pilots with <5,000 hours flying experience responded differently during the period of sleep deprivation than those with >5,000 hours flying experience. Those with less flying experience appeared to improve flying performance whilst those with more flying experience reported poorer performances with increasing time awake. These results potentially suggest flying experience may be a determining factor in flying performance in simulated flight during a period of continuous wakefulness. Several explanations are proposed for these findings. This interesting and stimulating flight task may have increased participants efforts to perform and overcome sleepiness (Harrison & Horne, 2000), particularly those with less flying experience who may have felt they had more to prove in this competitive and zealous industry. Additionally, those with more flying experience may have become somewhat complacent whilst those with less flying experience maintained more vigilant with increasing time awake. Complacency has been identified as a contributing factor to numerous incidents and accidents in civil aviation (Funk et al., 1999). Moreover, during training, pilots are required to amass 200 flying hours prior to obtaining a commercial pilot licence (IAA, 2018) and often do so in smaller aircrafts which can only be manually flown. Those with less flying hours will have completed their flying training more recently than those with more flying hours and so their manual flying skills may be better fine-tuned resulting in better performances in this flying task which required full manual flying (i.e., auto-pilot or auto-thrust were not engaged at any stage during the flight task).

Overall, following a period of continuous wakefulness, cognitive performance appeared to be significantly degraded relative to baseline conditions at the 20 hour mark during the period of sleep deprivation. During a normal day, in healthy rested people, alertness levels remain relatively stable throughout typical waking hours. When one has sufficient sleep, circadian fluctuations (i.e., near 24 hours) and variations in alertness (i.e., post-lunch dip) during normal waking hours are trivial and undetectable without highly sensitive tests. However, when continuous wakefulness is extended beyond about 16 hours, a majority of individuals begin to demonstrate considerable slowing of reaction time and poorer performances on tests of psychomotor vigilance (Goel et al., 2009). This may potentially suggest a ‘fatigue threshold’ although this would require further investigation. These performance impairments continue to worsen as wakefulness continues throughout the night (Killgore, 2010). The present study found impairments in performance began to become evident around 16 hours of continuous wakefulness. When an individual attempts to remain awake beyond 16 hours, there is an increase in the tension between mounting homeostatic pressure for sleep and motivation to fight sleep becomes greater resulting in an increase in variability in alertness and unreliable performance – i.e., the wake-state instability hypothesis (Doran et al., 2001). According to this hypothesis, the hallmark of sleep deprivation is this increased variability in performance as a result of the interaction of reciprocally inhibiting neurobiologic systems with one attempting to keep the individual awake while the other exerts pressure to fall sleep (Goel et al., 2009). According to Williamson and Feyer (2000), impairments in performance, which have been determined as the legal limit for safe driving performance, begin to occur at the 17 hours mark of continuous wakefulness and performance beyond this point is likely to be sufficiently impaired representing a considerably greater risk of injury. However, this figure is based on participants corresponding to a normal waking day (i.e., typically a mid to late evening bedtime depending on the time of rising). This may suggest that the implications for those operating shift-work or night-work hours may be even less prior to impairments in performance becoming evident.

7.1.5 Potential Indicators of Flight Performance

At present, no known ‘gold standard’ or threshold exists which can determine that an individual is too sleepy or fatigued to work/continue working. Fatigue detection measures can be subdivided under five subheadings as originally established by Dinges & Mallis (1998): (1) Readiness-to-perform and fitness-for-duty technologies; (2) Biomathematical models of human fatigue and performance; (3) Stimulus-response reaction tests; (4) Vehicle-based performance technologies and; (5) In-vehicle, on-line, operator status monitoring technologies (Dinges & Mallis, 1998; Mabbott et al., 1999). However, according to Heitmann et al., (2001) at present, the technology is expensive and its reliability is insufficient for widespread distribution. Basic cognitive tasks, which have received relatively limited investigation, may hold promise as potential indicators of impending precarious situations as a result of sleepy and fatigued operators (Lopez et al., 2012).

In Study 4, changes in situation awareness were found to be associated with changes in flight performance with increasing time awake. This is perhaps unsurprising considering that situational awareness is considered a critical criterion for the safe and effective operation of an aircraft (Sarter & Woods, 1991) and has also been identified as a causal factor in several aviation mishaps (Taylor, 1990). Endsley (1994; 1995b) developed a taxonomy for classifying and describing errors in situation. This taxonomy contains 3 levels and includes factors which affect situational awareness at each level; Level 1 – Failure to correctly perceive information; Level 2 – Failure to correctly integrate or comprehend information; Level 3 – Failure to project future actions or state of the system. Endsley (1995a) applied this taxonomy to an investigation of causal factors underlying aircraft accidents involving major air carriers in the United Stated based on NTSB accident investigation reports over a four year period. It was found that of the 71% of accidents that could be classified as containing a substantial human error element, 88% involved problems with situation awareness. Of the 32 situation errors identified among these accident descriptions, 23 (72%) were accredited to problems with Level 1 SA. Seven (22%) contained a Level 2 error whilst 2 (6%) involved a Level 3 error. Loss of situational awareness among pilots in the cockpit, particularly as regards failure to correctly perceive information, can have a catastrophic impact. The present research suggest that changes in situational awareness are related to changes in flying performance and may hold promise as a potential indicator of declining performance as a result of a sleepy or fatigued operator.

Whilst this area undoubtedly requires additional in-depth investigation there are various additional factors which will also need to be considered such as a method of measurement for situation awareness. Different methods of measuring situation awareness may impact findings as was suspected to be an influencing factor in the present research in which situation awareness was not found to be significantly impacted following 24 hours' sleep deprivation in Study 3 whilst it was found to be significantly impacted following 21 hours continuous wakefulness in Study 4. Study 3 employed the SART – a self-rating measure of awareness following completion of a basic computerised flight task whilst Study 4 required participants to answer questions regarding location, speed, heading, altitude and on TCAS pictures during the flight task. Subjective assessments of situation awareness only provide an insight in to individual interpretations of their performance in a particular task. However, one's subjective interpretation may significantly deviate from one's 'actual' situation awareness (Salmon et al., 2006). Self-rating methods of situation awareness may only indicate a participants confidence in their situational awareness as opposed to their actual awareness of which is proposed to be impaired by sleep deprivation (Alhola & Polo-Kantola, 2007; Endsley, 1995a). Harrison and Horne (2000) found that during 36 hours' sleep deprivation, participants became more confident their answers were correct with increasing time awake, with confidence increasing in strength with wrong answers. Therefore, caution is needed when employing measures of situational awareness particularly self-rating techniques.

According to Lopez et al., (2012), if one is attempting to predict performance on a complex task following a period of sleep deprivation, then employing a combination of two measures is a good place to start. Some other measures (e.g., multi-tasking ability; problem solving (time taken for mid-flight fuel calculations)) also indicated promise however, differences in flying performance between pilots with <5,000 hours flying experience and >5,000 hours flying experience resulted in somewhat inconclusive findings. The small sample size, as a result of access to this specialised population and the associated time and logistical constraints of the study, was a limiting factor. However, further investigation in to this area is strongly warranted. Prior to implementation of any of these measures in a real-world setting, they must demonstrate their ability to consistently and reliably predict performance at the individual level (Lopez et al., 2012).

7.1.6 Summary

Sleep disturbance and fatigue are a very serious and prevalent issue among commercial airline pilots flying for Irish-registered airlines. Furthermore, these high levels of sleep disturbance and fatigue influence safety in flight and negatively impact pilot mental health. The current regulations are proposed to be in breach of one or more aspects of fatigue with long working hours and duty periods potentially contributing to these high levels of sleep disturbance and fatigue observed in the present study. Furthermore, sleep deprivation and subsequent fatigue were found to significantly impair key competencies required by commercial airline pilots to successfully operate an aircraft. Significant impairments in performance became evident following 20 hours of continuous wakefulness. Whilst no known 'gold standard' or threshold exists which can determine that an individual is too tired or fatigued to work/continue working, measures of situational awareness appear to hold promise as a potential indicator of declining performance as a result of sleep loss and fatigue. This area warrants further investigation.

Chapter 8

Conclusions and Future Recommendations

8.1 Strengths and Limitations

This quantitative research employed both subjective and objective methods of data collection in order to explore and examine the influence of sleep deprivation and subsequent fatigue on incidents in flight and mental health and to investigate its effects on performance in commercial airline pilots. Study 1 and Study 2 employed an in-depth on-line survey. This survey was based on the foundations of prior surveys employed by other European pilot associations in order to explore the attitudes and experiences of sleep and fatigue among commercial airline pilots. The present survey utilised in this research counteracted some of the short comings of the previous surveys such as by utilising a time referenced period (i.e., "within the last 3 years"). However, self-report methods can contain limitations in the form of misunderstandings, social desirability and recall issues (Sallis & Saelens, 2000). Furthermore, in Study 2, which explored the relationship between self-reported depression or anxiety and factors relating to sleep, baseline or clinical levels of depression and anxiety were not pre-determined. However, both studies employed large sample sizes (*n*=954 and *n*=701, respectively) representing 32% and 23%, respectively, of the overall proposed population. Study 3 and Study 4 both utilised a relatively small sample size (i.e., *n*=7) as a result of access to this specialised population (in Study 4) and the associated time and logistical constraints of the study. Furthermore, this research was unable to further explore or draw any conclusions on the differences in gender in Study 4, which may or may not have had an influencing factor, due to the small sample size. Future studies employing larger sample sizes would aid in strengthening the present study's findings.

In Study 3 and Study 4 analogue measures were employed to examine the effects of sleep deprivation and fatigue on airline pilot competencies. These measures had to satisfy specific criteria such as having no learning effects/be repeatable, be relatively short in duration (to ensure it didn't induce fatigue), and be sensitive to fatigue. Some aviation-specific test batteries do exist such as the Multi-Attribute Task Battery (MATB) and they have been previously employed in sleep deprivation studies (Lopez et al., 2012). However, following extensive discussions with the authors of this research, these measures were deemed too simplistic among a professional pilot cohort and it was proposed that employment of alternative measures may provide more useful and beneficial findings. It was therefore decided to implement analogue measures of the key competencies under discussion and to amend measures to make them more relevant to an aviation environment where possible (i.e., utilising aviation-specific mathematical calculations).

Study 3 and Study 4 were conducted in a laboratory environment utilising a computerised flight simulator in order to measure flying performance. It would be unethical to deprive a pilot of sleep and get them to fly an aircraft. Therefore, the next viable option was to use a flight simulator. Due to financial constraints, this was not a feasible option for this study. Specialised computer-based flight simulator packages have been designed, such as the AIRSIM, which can also successfully collect data on pilots' flying performance. Additionally, the AIRSIM, which was employed in this research, has been found to offer the same basic functionality as the National Aerospace Laboratory's research flight simulator in Amsterdam (Groeneweg, 1998) and as such was deemed an excellent option to employ for this present research project.

To the knowledge of the authors, no previous studies have investigated the impact of sleep deprivation and fatigue on commercial airline pilots flying performance. In order to investigate flying performance, it was essential that a flight task be created which tested the key parameters of flying performance in commercial aviation (i.e., deviation from the green line, pitch, roll, bank, throttle input). Therefore, within this research, a flight task requiring pilots to fly a hold in airspace above Groening airport in Amsterdam (i.e., airspace that none of the participants would be familiar with flying) was developed and programmed to the AIRSIM computerised flight simulator. Whilst this study was the first in which this flying protocol was employed, it proved very successful. Furthermore, this now sets a solid platform on which further investigation can be conducted within the realm of sleep deprivation, fatigue and commercial aviation.

8.2 Directions for Future Research

This research concluded that sleep disturbance and fatigue appear to be widespread in Irish cockpits are can have serious consequences both on pilot performance and on pilot mental health and well-being. The current regulations implemented in February 2016 still appear to be in breach of various aspects of fatigue and therefore safety. The development and implementation of flight and duty time regulations which are based on sound scientific evidence regarding their ability to prevent pilot fatigue, and which also satisfy industry needs, are strongly required in this ever increasing 24/7 industry.

Various airline pilot-specific competencies, as identified in the ICAO manual of evidence-based practice, were found to be negatively impacted by sleep loss and fatigue. Going forward, future research should aim to employ more aviation-specific measures of these competencies (as opposed to analogue measures) with greater participant numbers to garner stronger and more real-world and specific findings. Furthermore, the development of real-time measures of these competencies which are applicable within a cockpit environment and do not interfere with a pilots primary duties is required. Such measures would aid in monitoring and providing up-to-date and real-time time information regarding pilots' performance in the cockpit.

Unexpectedly, in Study 4 it was found that pilots with +/- 5,000 hours flying experience responded differently during the period of sleep deprivation with those with less flying experience improving flying performance whilst those with more flying experience having poorer performances with increasing time awake. Whilst several proposals were made by the researchers as to why this may have occurred (i.e., nature of the task, influence of the industry), it is presently unknown and therefore warrants further investigation. Additional experimental studies exploring the effects of sleep loss and fatigue among commercial airline pilots with a range of flying hours experience need be conducted to aid in the explanation of this finding.

Early identification and warning of declining performance (as a result of sleep loss and fatigue) would reduce the likelihood of potential incidents and accidents (Williamson & Chamberlin, 2005). However, at present the technology is expensive and its reliability is insufficient for widespread distribution (Heitmann et al., 2001). The present research has demonstrated that basic cognitive measures, particularly situation awareness, show promise as potential indicators of decrements in flying performance as a result of sleep loss and fatigue. This area strongly requires further research. This coupled with the employment of real-world real-time measures, as discussed above, will aid in bridging the gap from research to real-world application and ultimately enhance safety in flight.

The research to date has somewhat identified that following a certain period of wakefulness (i.e., 16+ hours of continuous wakefulness), impairments in performance become evident. This provides the suggestion of a potential ‘fatigue threshold’. This area requires greater in-depth investigation with additional employment of physiological and neurological measures to provide a more in-depth exploration of events. Additionally, these findings would aid in contributing to the development of safe and effective flight and duty time regulations and promote a safer flying environment.

8.3 Conclusion

Today's commercial aviation flight operations work on pressurised 24/7 timetables. Commercial airline pilots are susceptible to sleep loss and fatigue with several European pilot surveys suggesting this is presently the case. Furthermore, sleep loss and fatigue are proposed to be a major risk to flight safety and a key cause of pilot error (Helmreich, 2000; Ramsey & McGlohn, 1997). This research examined the influence of sleep deprivation and associated fatigue on incidents in flight and mental health and investigated its effects on performance in commercial airline pilots.

This research found there to be very high incidences of sleep disturbance, feelings of fatigue, and micro-sleep events in the cockpit, amongst pilots flying for Irish-registered airlines, whilst working under the FTL's at the time of this research, which were proposed to be in breach of several aspects of fatigue (Moebus, 2008). Furthermore, the present regulations, which were implemented in February 2016, are proposed to still contain many of the shortcomings identified in the 2008 regulations. It is therefore potentially unsurprising that such high reports of sleep disturbance and fatigue among pilots were reported. Furthermore, this research concluded that Irish-registered commercial airline pilots who spend longer hours on duty in a typical week were found to 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. Furthermore, this proposed hours/incidents model found sleep disturbance and fatigue to play a key role in the pathway from working hours to incidents in flight. As well as impacting flight safety, sleep disruption and fatigue was also found to negatively impact pilot mental health and well-being. The present research found that commercial airline pilots self-reported sleep disturbance and fatigue significantly influenced self-reported depression or anxiety with those who reported higher incidences of sleep disturbance and fatigue being more likely to report feeling depressed or anxious. Further investigation in to the flight and duty time limitation regulations and its impact on pilots sleep and fatigue levels is required.

On further investigation of the influence of sleep deprivation and fatigue on pilot performance, it was found that following 24 hours' sleep deprivation, objective fatigue, attention, vigilance, hand-eye coordination, cognitive flexibility, problem-solving, multi-tasking ability, perceived workload and situational awareness were significantly negatively impacted. While flying performance did indicate trending declines in performance, this was not found to be significantly impaired. It was proposed that pilots may be able to maintain flying performance by heavily relying on training and flying experience that can overcome large increases in sleep loss and fatigue which considerably degrades cognitive performance (Previc et al., 2009). Changes in situation awareness was found to be associated with changes in flying performance during the period of continuous wakefulness. Further investigation is required in to the use of situation awareness, and additional measures, as potential indicators of impending precarious situations as a result of sleep loss and fatigue. Moreover, overall cognitive performance appeared to be significantly degraded relative to baseline conditions at the 20 hour mark however, some impairments did become evident following 17+ hours of continuous wakefulness. This may potentially suggest a 'fatigue threshold' and as such warrants further investigation.

The number of serious accidents as a result of operator error in various industries due to sleep loss and fatigue is large and appears to be increasing (Lopez et al., 2012). The early detection of sleep deprived and fatigued operators will aid in eradicating these incidents and accidents. Enhancing our understanding and identifying and mitigating sleep deprivation and fatigue among commercial airline pilots through implementation of safe and effective FTL regulations and real-time indicators of flying performance will aid in promoting both flight safety and pilot mental health and well-being.

According to Lindgren and colleagues (2006), sleep is considered a human factor which influences flying performance. However, sleep disturbance and fatigue has been found to be widespread among commercial airline pilots. Cognitive performance appeared to be significantly degraded relative to baseline values between the 18 – 20 hour mark of continuous wakefulness in the present research however, reductions in performance became evident earlier (i.e., 15 hours wakefulness). Current regulations permit pilots to fly up to 15 hours in a single duty period under certain circumstances. In these instances, it is likely that the pilot is already in their 17th hour of waking. According to Williamson and Feyer (2000), the 17th hour mark of continuous wakefulness is the legal limit for safe driving performance following which performance beyond this point is likely to be sufficiently impaired. However, current flying regulations within Europe allow situations to arise which could and, according to the findings in Study 1, does occur, in which pilots are operating an aircraft in to their 17th hour of wakefulness. The development and implementation of sound scientifically-driven flight and rest regulations are greatly required to ensure successful safeguarding against pilot fatigue.

Furthermore, greater awareness, emphasis and education are needed among pilots regarding healthy and safe sleep and rest practices.

8.4 Impact of the Research

This research identified a work hours/incident model identifying the interplay of factors (i.e., sleep disruption, feelings of fatigue, micro-sleep events, errors in flight) contributing to incidents within the aviation industry. Establishing this foundation provides a base on which to further investigate the intricate and complex relationship between duty hours and incidents in flight. Furthermore, this research was successful in highlighting the frequency and magnitude of sleep disturbance and fatigue among Irish-registered commercial airline pilots working under the current FTL regulations. Raising awareness of the prevalence of these serious issues will promote and encourage further investigation in to this area.

Mental health issues among pilots have been identified, but the extent, origins, or degree of these problems among active airline pilots is currently unknown (Butcher, 2002). This research explored the prevalence of self-reported depression or anxiety among Irish-registered commercial airline pilots and the potential influence of job-related sleep disruption and fatigue on these factors. It was concluded that those who reported higher incidences of sleep disturbance and fatigue were more likely to report feeling depressed or anxious. This research increased awareness and understanding of the insidious and prevalent threat of sleep loss and fatigue not only on pilot performance in the cockpit but on pilot health and well-being also.

Sleep loss and fatigue pose a very serious threat to flight safety. This research was successful in highlighting the impact of a bout of acute sleep deprivation and subsequent fatigue on aviation-specific competencies and flying performance. Furthermore, this research was able to map changes in these measures with increasing time awake and identify the point at which performance became significantly impaired. This overall research aids in enhancing our knowledge of the impact of sleep deprivation and fatigue in the aviation domain, promoting future accident prevention and safety.

As previously mentioned, to the knowledge of the authors, no prior research has explored the effects of sleep deprivation and fatigue on commercial airline pilots flying performance. Whilst research of this nature has been investigated in a military context, it has not been conducted in a commercial aviation context. Therefore, this research developed and programmed a flight profile on a computerised flight simulator (i.e., AIRSIM) as a method of measuring commercial airline pilots flying performance. This measure provides a sound base on which future research can be conducted as a means of measuring flying performance among commercial airline pilots.

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Appendices

Appendix A: Ethics (Survey) – Letter of Approval

Ollscoil Chathair Bhaile Átha Cliath
Dublin City University

DCU

Dr. Giles Warrington
School of Health and Human Performance

17th September 2012

REC Reference:	DCUREC/2012/155
Proposal Title:	**Survey Investigating Attitudes and Experiences of Commercial Airline Pilots to Fatigue and the Current Flight Time Limitations (FTL's)**
Applicants:	Dr. Giles Warrington, Ms. Anna Donnla O'Hagan

Dear Giles

This research proposal qualifies under our Notification Procedure, as a low risk social research project. Therefore, the DCU Research Ethics Committee approves this research proposal. Materials used to recruit participants should note that ethical approval for this project has been obtained from the Dublin City University Research Ethics Committee. Should substantial modifications to the research protocol be required at a later stage, a further submission should be made to the REC.

Yours sincerely,

DCU Research & Innovation

Dónal O'Mathúna

Dr. Donal O'Mathuna
Chairperson
DCU Research Ethics Committee

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Appendix B: Survey (Study 1 & Study 2)

Survey Investigating Attitudes and Experiences of Commercial Airline Pilots to Fatigue and the Current Flight Time Limitations (FTL's)

Dr. Giles Warrington
Anna Donnla O'Hagan

School of Health and Human Performance
Dublin City University

Background

This survey has been specifically designed to examine the attitudes and experience of pilots, flying for Irish registered airlines, to fatigue and the current Flight Time Limitations (FTL's).

The current European Regulations concerning FTL's for flight crew – EU-OPS subpart Q – came into effect in July 2008. All questions in this pilot questionnaire should only be answered with reference to the period from July 2008 to the present day.

Prior to completing this survey you will need to know your:

- *Number of and length of duties over a typical month*
- *Duty hours over a typical week*
- *Average duty hours per week in your last 28 days*
- *Duration of rest period between working periods/weeks*

Please Note: All questions relating to duty time (duty periods) refer to the time from when one reports for duty to the time when they are free of all duties. It does not refer to flight time (flight duty periods).

The survey takes approximately 15 minutes to complete. All raw data will only be available to the DCU research team who ***shall not have any means of accessing the identity of any participants****. All responses are anonymous and will be dealt with on a strictly confidential basis.*

Thank you for taking the time to complete this survey.

Question 1. Please indicate your employer:

Please note: This purpose of this question is solely to allow for comparison between individual Airlines. **All answers are anonymous and will remain strictly confidential.**

Aer Arann	
Aer Lingus	
City Jet	
Ryanair	
Other	
Prefer not to say	

Question 2. Please indicate your position:

Captain	
1st/2nd Officer	
Prefer not to say	

Question 3. Please indicate your gender:

Male	
Female	
Prefer not to say	

Question 4. Please indicate your age:

<25 yrs	
26 – 35 yrs	
36 – 45 yrs	
46 – 55 yrs	
56 – 65 yrs	
Prefer not to say	

Question 5. Please tick the box that best describes your living situation:

Living with partner	
Living alone	
Living with parents/friends	
Prefer not to say	

Question 6. If relevant, please indicate the number and ages of children living in your home:

Number of Children	
Ages of Children	
Prefer not to say	

Question 7. Please indicate whether you work full-time or part-time, and if part-time please indicate what % of a full-time hour contract you work (i.e. assume a 5-day week is full-time, 3-day week = 60% etc.)

Full time	

Part time	

% of full time contract	

Question 8. Please indicate whether you are permanent or on contract:

Permanent	
Contract	
Prefer not to say	

Question 9. Please indicate how many times per typical calendar month you operate duties of the following lengths. (Tick one in each row)

	Times per month	1	2-3	4-5	6-7	≥8	Never	Don't know
Duty Length	**≤8 hours**							
	>8 but ≤10 hours							
	>10 but ≤12 hours							
	>12 but ≤14 hours							
	>14 hours							

Question 10. How many hours do you spend on duty in a typical week? (Tick the option that best describes your situation).

If you don't fly roughly the same amount each week, take the typical average figure in a 28-day period.

<25 hours	
25-30 hours	
31-35 hours	
36-40 hours	
41-45 hours	
45-50 hours	
>50 hours	

Question 11. On average, how many hours did you spend on duty *per week* during your last 28 days?

Less than 45 hours	
More than 45 hours	
More than 50 hours	
More than 60 hours	
Other/don't know	

Question 12. In the last 3 years, have you ever started a new work period/week with only 36 hours rest between work periods/weeks? (According to Subpart Q, 36 hours is the minimum rest break that can be taken between each work period/week)

Never. I always have more rest between work periods/weeks	
Yes, it happens now and then	
Yes, it happens often	
Don't know/no opinion	

Question 13. ICAO has stated that "Flight time, flight duty period, duty period limitations and rest requirements are established for the *sole purpose* of ensuring that the flight crew and the cabin crew members are performing at an *adequate level of alertness for safe flight operations*".

What level of protection do you consider the current regulations contained in EU-OPS Subpart Q provide flight and cabin crew against the threats posed by fatigue?

No protection at all	
Very low level of protection	
Low level of protection	
A high level of protection	
A very high level of protection	
Don't know/no opinion	

Question 14. What is/are your greatest concern(s), with the current Flight Time Limitations (Subpart Q)? (Please number in level of priority, with 1= highest, 2 next highest…., the items that concern you).

Maximum Length of Duty Day (13 hours)	
Amount of Duty hours per week	
Amount of rest between duties (min 10 hours)	
Amount of rest between work periods (min 36 hours)	
Extended duties	
Expectation to use Captain's Discretion	
Split Duties	
Perceived lack of appropriate Regulatory Oversight by IAA	
Other (Please specify)	

Question 15. In the past 3 years, have you ever extended, or had your duty extended using Captain's Discretion?

No, never	
Yes, once	
Yes, now and then/rarely (<once per month)	
Yes, often (> once per month)	
Don't know/no opinion	

Question 16. In the past 3 years, have you ever experienced a situation where your employer has instructed you, or put you under pressure, to extend your duty using Captain's Discretion?

No, never	
Yes, once	
Yes, now and then/rarely	
Yes, often	
Don't know/no opinion	

Question 17. ***Fatigue refers to a physiological state of diminished mental capacity caused by insufficient sleep, extended number of waking hours and/or workload. Some symptoms of fatigue include tiredness, reduction in effort and decreased efficiency.***

In the past 3 years, have you ever felt so tired/fatigued in-flight, that you felt you should not be on active duty in the cockpit?

No, never	
Yes, once	
Yes, now and then/rarely	
Yes, often	
Don't know/no opinion	

Question 18. Have you ever had an incident outside of work that you believe was due to fatigue caused primarily by your occupation?

No	
Yes	

If you answered yes, please give brief details:____

Question 19. Do you feel that you are mentally more alert and ready to perform your duties as a pilot *early in the morning* or *late in the evening*?

Early Morning	
Late Evening	
No preference	

Question 20. Based on your response to question 15, does your company facilitate requests for either early or late starting duties?

Requests facilitated always	
Requests facilitated sometimes	
Requests facilitated rarely	
No facility to request	

Question 21. ***A micro-sleep event is best described as "a fleeting, uncontrollable episode of sleep which may last from a fraction of a second up to 10 seconds". Some symptoms of micro-sleep include increased amount of blinking, nodding head and drooping eyelids.***

In the last 3 years, have you ever experienced a micro-sleep event, or fallen asleep while

actively on duty in the cockpit, without prior agreement with the other pilot?

No, never	
Yes, once	
Yes, now and then/rarely	
Yes, often	
Don't know/no opinion	

Question 22. In the past 3 years, have you ever made what you consider an error(s) affecting flight safety that you attribute solely to fatigue while on active duty in the cockpit? (i.e. an error that did not lead to an incident).

No	
Yes	
Don't know/no opinion	

If you answered yes, please specify what type of error(s):_____________________________

Question 23. In the past 3 years, while on duty have you ever been involved in an incident(s) where you felt that fatigue of you and/or your pilot colleague was a contributory factor?

No	
Yes	
Don't know/no opinion	

If you answered yes, please specify what kind of incident(s):____________________________

Question 24. If you believed yourself to be "unfit for flight" due to fatigue caused by your working schedule or work as a pilot, would you "call in fatigued"?

No	
Yes	
Don't know/no opinion	
No, as this is not an option in my airline	

If you answered no, please specify why:____

Question 25. In the past 3 years, have you ever reported "unfit for flight" because you were suffering from the effects of fatigue, i.e. "called in fatigued"?

No, never	
Yes, once	
Yes, now and then/rarely	
Yes, often	
Don't know/no opinion	

Question 26. In the past 3 years, have you ever reported "unfit for flight" ***claiming that you were sick, but in fact you were "unfit for flight" due to tiredness or fatigue.***

No	
Yes, once	
Yes, now and then/rarely	

Yes, often	
Don’t know/no opinion	

Question 27. If you answered yes to Question 26, can you indicate why you chose not to report “unfit for flight” due to fatigue? (Please number in level of priority, with 1= highest, 2 next highest…., the factors that influenced your decision).

Pride	
Fear of reprimand by employer	
Fear of stigmatization by employer	
Fear of stigmatization by colleagues	
Feeling of lack of support from employer	
Felling of lack of support from colleagues	
Fatigue caused by factors other than flying duties	
Loss of earnings	
Other (please specify)	

Question 28. In the past 12 months, have you ever suffered from feelings of being burned out, exhausted, depressed or anxious?

	Burned out / Exhausted	Depressed / Anxious
No		
Yes, once		
Yes, now and then/rarely		
Yes, often		
Don’t know/no opinion		

Have you experienced any other similar feelings? If yes, please specify:__________________

Question 29. In the past 3 years, do you consider your work as a commercial pilot negatively influences your ability to adopt normal sleeping patterns that allow proper rest on a regular basis?

No	
Yes, a few times/month	
Yes, several times/month	
Yes, several times/week	
Don’t know/no opinion	

Question 30. To what extent do you believe that your employer and the Irish Aviation Authority take the associated risks posed by tired pilots seriously?

	Your employer	Irish Aviation Authority
Very seriously		
Seriously		
Mildly concerned		
Not concerned at all		
Don’t know		

Thank you for completing this survey.

Appendix C: Additional Information on Logistic Regression Analysis (Study 2)

The depression and anxiety measure arose from a question asked in the 30-item survey ("In the past 12 months, have you ever suffered from feelings of being…depressed or anxious"). Participants were required to answer this along a continuum ranging from 'no, never' to 'yes, often'. These results were then conflated in to a dichotomous variable (i.e., 'no, never' = no; 'yes, once' + 'yes, now and then/rarely' + 'yes, often' = yes). This would be considered an unnaturally dichotomous variable as there are only two values for this variable (i.e., yes; no) in our data but there may possibly be more in the real world which in turned could be viewed as a limitation of the research. However, it was decided to dichotomise this variable for simplicity and ease of comprehension of the results for the reader. On identification of meaningful and significant findings, it is encouraged that future research should aim to further explore these variables in their continuous state.

Binary logistic regression analysis was conducted in Study 2 in order to investigate the differences in self-reported depression or anxiety associated with duty hours among European-registered commercial airline pilots, and then to further investigate the extent to which these differences could be explained, initially by individual demographic characteristics, and subsequently by pilots sleep and fatigue experiences. This analysis was employed in order to predict the relationship between predictors (i.e., demographic factors and sleep and fatigue experiences) and a predicted variable where the dependent variable is binary (i.e., self-reported depression or anxiety) (O'Connell, 2006). Therefore, it estimates the probability of a (binary) response based on one or more predictor (i.e., independent) variables. Employing a binary logistic regression analysis allow us to explore a dependence structure, with a dependent variable and a set of explanatory variables (O'Connell, 2006).

A hierarchical logistic regression analysis could have been performed in this instance. The hierarchical logistic regression differs from the previous analysis in that it takes in to account the relationship between some control independent variables and the dependent variable. A hierarchical logistic regression analysis utilising the data in Study 2 has been conducted below:

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	14.338	6	.026
	Block	14.338	6	.026
	Model	14.338	6	.026

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	952.140[a]	.020	.027

a. Estimation terminated at iteration number 3 because parameter estimates changed by less than .001.

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	Duty_Hours			13.944	6	.030			
	Duty_Hours(1)	-.511	.462	1.224	1	.269	.600	.242	1.484
	Duty_Hours(2)	.035	.331	.011	1	.916	1.036	.542	1.981
	Duty_Hours(3)	-.007	.313	.000	1	.983	.993	.537	1.835
	Duty_Hours(4)	.248	.307	.653	1	.419	1.281	.702	2.336
	Duty_Hours(5)	.637	.322	3.911	1	.048	1.891	1.006	3.557
	Duty_Hours(6)	.538	.363	2.196	1	.138	1.713	.841	3.491
	Constant	-.035	.265	.018	1	.895	.966		

a. Variable(s) entered on step 1: Duty_Hours.

In Model 1 it was concluded that those who spend longer hours on duty are significantly more likely to report feeling depressed or anxious with those who reported typically spending 45 – 50 hours on duty per week being 1.8 times significantly more likely to report feeling depressed or anxious in the last 12 months relative to those who typically reported spending <25 hours on duty per week (odds ratio [OR] = 1.89, 95% confidence interval [CI] = [1.00, 3.55]).

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	13.692	11	.251
	Block	13.692	11	.251
	Model	28.030	17	.045

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	938.448[a]	.039	.052

a. Estimation terminated at iteration number 4 because parameter estimates changed by less than .001.

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	Duty_Hours			12.845	6	.046			
	Duty_Hours(1)	-.419	.470	.793	1	.373	.658	.262	1.654
	Duty_Hours(2)	.106	.338	.098	1	.755	1.111	.573	2.156
	Duty_Hours(3)	.034	.319	.011	1	.915	1.035	.553	1.935
	Duty_Hours(4)	.298	.314	.903	1	.342	1.347	.728	2.491
	Duty_Hours(5)	.694	.331	4.383	1	.036	2.002	1.045	3.833
	Duty_Hours(6)	.564	.372	2.293	1	.130	1.757	.847	3.644
	Position(1)	.095	.190	.247	1	.619	1.099	.757	1.595
	Gender(1)	-.961	.430	4.995	1	.025	.383	.165	.889
	Age			4.295	4	.368			
	Age(1)	-.390	.607	.411	1	.521	.677	.206	2.227
	Age(2)	.029	.554	.003	1	.958	1.030	.348	3.048
	Age(3)	.176	.553	.101	1	.750	1.192	.404	3.524
	Age(4)	.376	.580	.420	1	.517	1.456	.467	4.539
	Living_Situation			2.560	3	.465			
	Living_Situation(1)	.471	.370	1.625	1	.202	1.602	.776	3.307
	Living_Situation(2)	.492	.408	1.459	1	.227	1.636	.736	3.637
	Living_Situation(3)	.692	.433	2.555	1	.110	1.997	.855	4.664
	Employment(1)	.540	.507	1.131	1	.288	1.715	.635	4.636
	Contract(1)	-.313	.178	3.097	1	.078	.731	.516	1.036
	Constant	-.108	.938	.013	1	.909	.898		

a. Variable(s) entered on step 1: Position, Gender, Age, Living_Situation, Employment, Contract.

In Model 2, when incorporating demographic factors in to the model (i.e., gender, age, position, living situation, contract, and employment), it was concluded that males were 62% less likely to report feeling depressed or anxious in the last 12 months relative to females (OR = 0.383, 95% CI = [0.16, 0.88]), when controlling for typical duty hours.

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	108.280	9	.000
	Block	108.280	9	.000
	Model	136.310	26	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	830.168[a]	.177	.236

a. Estimation terminated at iteration number 4 because parameter estimates changed by less than .001.

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	95% C.I.for EXP(B) Upper
Step 1[a]	Duty_Hours			3.602	6	.730			
	Duty_Hours(1)	.289	.517	.313	1	.576	1.335	.485	3.679
	Duty_Hours(2)	.344	.371	.859	1	.354	1.411	.681	2.921
	Duty_Hours(3)	.213	.350	.372	1	.542	1.238	.624	2.456
	Duty_Hours(4)	.451	.343	1.732	1	.188	1.570	.802	3.075
	Duty_Hours(5)	.562	.363	2.402	1	.121	1.755	.862	3.574
	Duty_Hours(6)	.205	.406	.254	1	.614	1.227	.554	2.718
	Position(1)	.088	.208	.180	1	.672	1.092	.727	1.642
	Gender(1)	-1.273	.461	7.626	1	.006	.280	.113	.691
	Age			2.840	4	.585			
	Age(1)	.059	.672	.008	1	.931	1.060	.284	3.958
	Age(2)	.352	.613	.330	1	.566	1.422	.427	4.731
	Age(3)	.508	.613	.687	1	.407	1.662	.500	5.530
	Age(4)	.658	.641	1.055	1	.304	1.932	.550	6.782
	Living_Situation			2.442	3	.486			
	Living_Situation(1)	.556	.396	1.973	1	.160	1.745	.802	3.793
	Living_Situation(2)	.593	.437	1.843	1	.175	1.809	.769	4.257
	Living_Situation(3)	.698	.465	2.258	1	.133	2.010	.809	4.998
	Employment(1)	.611	.567	1.159	1	.282	1.842	.606	5.597
	Contract(1)	-.317	.195	2.640	1	.104	.728	.496	1.068
	Fatigue			23.974	3	.000			
	Fatigue(1)	-1.686	.361	21.767	1	.000	.185	.091	.376
	Fatigue(2)	-1.288	.337	14.636	1	.000	.276	.143	.534
	Fatigue(3)	-.849	.256	10.966	1	.001	.428	.259	.707

Microsleeps			8.908	3	.031			
Microsleeps(1)	-.883	.300	8.658	1	.003	.414	.230	.745
Microsleeps(2)	-.510	.324	2.473	1	.116	.601	.318	1.134
Microsleeps(3)	-.533	.239	4.967	1	.026	.587	.367	.938
Sleep			13.710	3	.003			
Sleep(1)	-1.153	.362	10.176	1	.001	.316	.155	.641
Sleep(2)	-.801	.253	10.062	1	.002	.449	.274	.736
Sleep(3)	-.625	.240	6.795	1	.009	.535	.335	.856
Constant	1.574	1.044	2.275	1	.131	4.828		

a. Variable(s) entered on step 1: Fatigue, Microsleeps, Sleep.

Finally, in Model 3, when controlling for both duty hours and demographic factors, it was concluded that those who reported never feeling too fatigued to be on active duty in the cockpit were 58% less likely to report feeling depressed or anxious in the last 12 months relative to those who reported often feeling too fatigue to be on duty (OR = 0.42, 95% CI = [0.25, 0.70]). Additionally, those who reported often experiencing microsleeps in the cockpit were 58% more likely to report feeling depressed or anxious in the last 12 months relative to those who reported never experiencing microsleeps in the cockpit (OR = 0.58, 95% CI = [0.36, 0.93]). Furthermore, those who reported experiencing sleep disturbance due to work several times per week were 53% more likely to report feeling depressed or anxious (OR = 3.16, 95% CI = [1.56, 6.43]) compared with those who reported never experiencing sleep disturbance due to their occupation (OR = 0.53, 95% CI = [0.33, 0.85]).

Appendix D: Ethics (Overall PhD) – Letter of Approval

Ollscoil Chathair Bhaile Átha Cliath
Dublin City University

Dr. Giles Warrington
School of Health and Human Performance

13th December 2013

REC Reference: DCUREC/2013/222

Proposal Title: **The Effects of Current Flight Time Limitations (FTL's) and Sleep Deprivation on Objective and Subjective Fatigue Levels and Flying Skills of Commercial Pilots Flying for Irish-Registered Airlines**

Applicants: Dr. Giles Warrington, Dr. Johann Issartel, Ms. Anna Donnla O'Hagan

Dear Giles,

Further to expedited review, the DCU Research Ethics Committee approves this research proposal. Materials used to recruit participants should note that ethical approval for this project has been obtained from the Dublin City University Research Ethics Committee. Should substantial modifications to the research protocol be required at a later stage, a further submission should be made to the REC.

Yours sincerely,

DCU Research & Innovation

Dónal O'Mathúna

Dr. Donal O'Mathuna
Chairperson
DCU Research Ethics Committee

Taighde & Nuálaíocht Tacaíocht
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Appendix E: Plain Language Statement (Study 3)

DUBLIN CITY UNIVERSITY
PLAIN LANGUAGE STATEMENT

I. **Introduction to the Research Study**

Project Title: An analysis of the effects of acute sleep deprivation on pilot skills

Fatigue is a very serious issue which is proposed to interfere with pilots cognitive (e.g. ability to make decisions, attention, vigilance), physiological (e.g. respiration rate, body temperature) and psychological (e.g. mood) functioning. It is also proposed to interfere with pilots' flying skills. This project aims to investigate the effects of fatigue (implemented via an acute bout of sleep deprivation) on subjects' cognitive, physiological and psychological function. It will also investigate the effects of fatigue on a series of pilot-specific skills as well as flying performance.

II. Details of what involvement in the Research Study will require

This project will involve completing a battery of cognitive tests four times over a 24 hour period. There will be two separate 24 hour testing periods, one with normal 8 hours sleep and one with 24 hour sleep deprivation. Physiological data will be gathered using a body worn tracking system – the Equivital System. This device record respiratory rate, skin body temperature and heart rate variability throughout the 24 hour period. Furthermore, an additional physiological monitoring device – a SenseWear Armband will also be worn throughout the 24 hour testing period. This will be used as a measure of energy expenditure. Furthermore, a battery of tests consisting of a series of questionnaires and task-based tests will be performed in order to determine the effects of fatigue on cognitive function, psychological function and pilot specific flying skills. These tests will measure mood, situation awareness, ability to manage workload, problem-solving and decision-making and ability to recall previously learned information. Flying performance will be determined based on performance on a Microsoft computer-based flight task.

III. Potential risks to participants from involvement in the Research Study (if greater than that encountered in everyday life)

With any bout of sleep deprivation, there is an increased likelihood you will experience irritability, tiredness and potentially grogginess. Obtaining at least two good night's sleep (e.g. at least 8 hours) the following day/night will help to restore your energy levels to their original levels.

IV. Benefits (direct or indirect) to participants from involvement in the Research Study

Through this research a participant may be able to request their cognitive test scores which can give them a profile of how well they performed. This may highlight areas of weaknesses that could be worked on. The participants may also get access to their scores after sleep deprivation which may show the effects of the bout of sleep deprivation.

V. Advice as to arrangements to be made to protect confidentiality of data, including that confidentiality of information provided is subject to legal limitations

All data will be kept in the strictest of confidence with access being limited to the investigators, Dr. Giles Warrington, Anna Donnla O'Hagan, and Eoghan McGinley. In accordance with DCU policy all data will be kept on-site in DCU in a locked secure area.

VI. Advice as to whether or not data is to be destroyed after a minimum period

After a 5 year period, if participants do not wish to have their data returned, or do not contact the investigators, all data will be destroyed in accordance with DCU policy.

VII. Statement that involvement in the Research Study is voluntary

If at any point during your participation in the study you feel as if you wish to leave, this is not a problem. You are under no obligation to stay involved if you do not wish too. Please make sure to contact the investigators if you are unable or unwilling to continue in the project so as we can address an issues within the project.

If participants have concerns about this study and wish to contact an independent person, please contact:

The Secretary, Dublin City University Research Ethics Committee, c/o Office of the Vice-President for Research, Dublin City University, Dublin 9. Tel 01-7008000

Appendix F: Informed Consent (Study 3)

DUBLIN CITY UNIVERSITY
INFORMED CONSENT

I. Research Study Title

Project Title: An analysis of the effects of acute sleep deprivation on pilot skills

Fatigue is a very serious issue which is proposed to interfere with pilots cognitive (e.g. ability to make decisions, attention, vigilance), physiological (e.g. respiration rate, body temperature) and psychological (e.g. mood) functioning. It is also proposed to interfere with pilots' flying skills. This project aims to investigate the effects of fatigue (implemented via an acute bout of sleep deprivation) on subjects' cognitive, physiological and psychological function. It will also investigate the effects of fatigue on flying performance.

II. Clarification of the purpose of the research

- To examine the effect of fatigue, implemented via an acute bout of 24 hrs sleep deprivation, on cognitive, physiological and psychological function
- To examine the effect of fatigue, implemented via an acute bout of 24 hrs sleep deprivation, on flying performance

III. Confirmation of particular requirements as highlighted in the Plain Language Statement

This project will involve completing a battery of tests four times over a 24 hour period. There will be two separate 24 hour testing periods, one with normal 8 hours sleep and one with 24 hour sleep deprivation. Physiological data will be gathered using a body worn tracking system – the Equivital System. This device record respiratory rate, skin body temperature and heart rate variability throughout the 24 hour period. Furthermore, an additional physiological monitoring device – a SenseWear Armband will also be worn throughout the 24 hours testing period. This will be used as a measure of energy expenditure. A battery of tests consisting of a series of questionnaires and task-based tests will also be performed in order to determine the effects of fatigue on cognitive function, psychological function and pilot specific flying skills. These tests will measure mood, situation awareness, ability to manage workload, problem-solving and decision-making and ability to recall previously learned information. Flying performance will be determined based on performance on a Microsoft computer-based flight task.

<u>Participant – please complete the following (Circle Yes or No for each question)</u>
I have read the Plain Language Statement (or had it read to me)
Yes/No
I understand the information provided
Yes/No
I have had an opportunity to ask questions and discuss this study
Yes/No
I have received satisfactory answers to all my questions
Yes/No
I am aware that my interview will be audiotaped
Yes/No

IV. Confirmation that involvement in the Research Study is voluntary

If at any point during my participation in the study I feel as if I wish to leave this is not a problem. I am under no obligation to stay involved if I do not wish too. Please make sure to contact the investigators if I are unable or unwilling to continue in the project so as they can address any issues within the project

V. Advice as to arrangements to be made to protect confidentiality of data, including that confidentiality of information provided is subject to legal limitations

All data will be kept in the strictest of confidence with access being limited to the investigators, Dr. Giles Warrington, Anna Donnla O'Hagan and Eoghan McGinley. In accordance with DCU policy all data will be kept on-site in DCU in a locked secure area.

VI. Any other relevant information

N/A

VII. Signature:

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project

Participants Signature:______________________________________

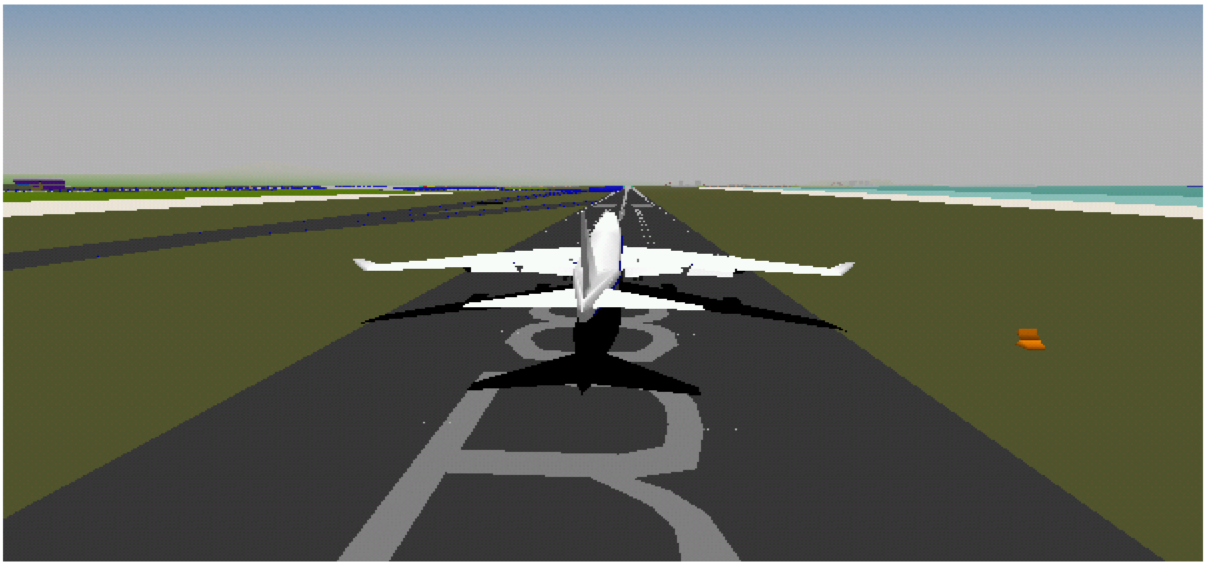
Name in Block Capitals:_____________________________________

Witness: ____

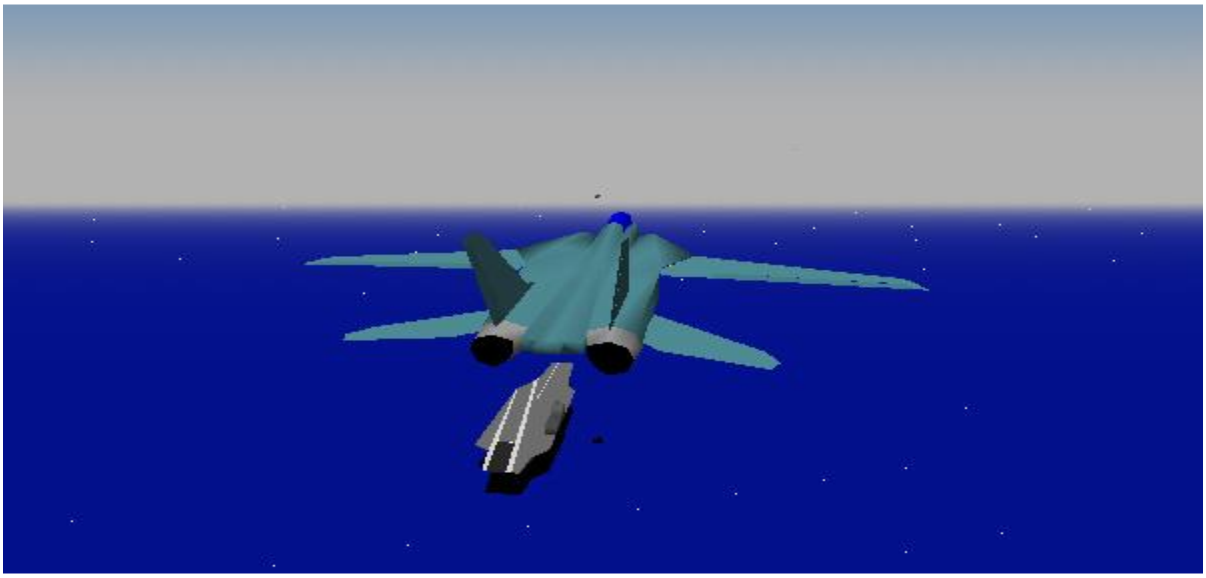
Date:____

Appendix G: YSFlight Simulator (Study 3)

In Study 3 participants were required to perform a basic computerised flight simulator task on a YSFlight Simulator (Version 20130805). Participants were required to land an aircraft as quickly as possible using a pre-set scenario [Landing Practice – Level 1: straight in, wind-calm, good visibility]. The task required participants to successfully land the aircraft on the runway in as short a time as possible (Graphic 1). The task commenced with the aircraft mid-flight and with the runway directly in front of the aircraft (Graphic 2). Instructions for the flight simulator were read out to participants prior to each trial and a copy of the instructions was left in view of participants for reference if needed.



Graphic 1.



Graphic 2.

Flight Simulator Instructions

The aim of this test is to successfully land the aircraft in as short a time as possible. The controls for the aircraft are as follows:

- Q = Engine On
- A = Engine Off
- G = Landing Gear Down/Up
- Mouse = Directional Control
  - Move the mouse up to direct the aircraft downwards
  - Move the mouse down to direct the aircraft upwards

The curved arch and arrow on the centre of the screen represent how level the aircraft is, i.e. is the aircraft tilted to the left or right, or is it centred. In order to get the plane to fly straight the arrow must be in the centre of this arch. The centre of the screen shows the angle of elevation of the plane in terms of degrees:

- 0 represents a level plane
- + figure represents the plane gaining altitude
- - figure represents the plane losing altitude

The left hand side of the screen shows the speed of the aircraft and the altitude of the aircraft is located on the right hand side of the screen.

Appendix H: Means and SD's of All Variables (Study 3)

Table H.1 and H.2 provide the Mean and Standard Deviation results for the mood, and fatigue and airline pilot-specific skill scores, respectively.

Table H.1.: Mean (±SD) subjective ratings of Tension, Depression, Anger, Fatigue, Vigour, Confusion and Total Mood Disturbance during the 'Sleep' and 'No Sleep' Conditions

Dependent Variables	Duration of Wakefulness (h)			
	0	8	16	24
Tension				
'Sleep'	13.42 ± 3.82	13.14 ± 3.80	14.00 ± 4.35	12.85 ± 2.91
'No Sleep'	13.57 ± 4.92	15.85 ± 5.95	15.28 ± 3.72	16.14 ± 4.05
Depression				
'Sleep'	17.00 ± 3.46	18.00 ± 4.72	18.42 ± 4.54	16.42 ± 2.57
'No Sleep'	17.57 ± 4.31	20.57 ± 6.52	17.85 ± 4.63	22.28 ± 6.31
Anger				
'Sleep'	15.71 ± 4.53	15.85 ± 4.52	15.57 ± 3.77	15.00 ± 3.65
'No Sleep'	13.57 ± 1.13	16.57 ± 4.72	14.00 ± 1.73	20.14 ± 6.59
Fatigue				
'Sleep'	8.85 ± 2.60	11.14 ± 5.42	13.14 ± 5.11	12.14 ± 3.33
'No Sleep'	9.57 ± 4.15	9.71 ± 2.49	13.42 ± 4.99	22.14 ± 5.49
Vigour				
'Sleep'	24.00 ± 5.50	23.71 ± 6.18	19.57 ± 5.53	18.42 ± 5.91
'No Sleep'	24.00 ± 6.50	21.00 ± 5.16	21.28 ± 6.42	13.28 ± 5.15
Confusion				
'Sleep'	12.42 ±1.39	12.00 ± 3.36	14.28 ± 3.30	14.42 ± 3.20
'No Sleep'	11.42 ± 2.43	14.00 ±1.73	14.14 ± 2.96	15.71 ± 3.03
Total Mood Disturbance				
'Sleep'	43.42 ± 19.19	46.42 ± 24.17	55.85 ± 21.57	52.42 ± 18.39
'No Sleep'	41.71 ± 19.99	55.85 ± 21.57	53.42 ± 21.20	83.42 ± 25.75

Table H.2.: Mean (±SD) results of Fatigue and Airline Pilot-Specific Skill Scores during the 'Sleep' and 'No Sleep' Conditions

Dependent Variables	Duration of Wakefulness (h)			
	0	**8**	**16**	**24**
Fatigue Severity Scale				
'Sleep'	27.28 ± 5.46	26.85 ± 7.73	29.57 ± 8.88	27.85 ± 8.49
'No Sleep'	27.14 ± 6.20	27.14 ± 5.52	29.85 ± 8.27	34.85 ± 8.82
PVT: Lapses in Attention				
'Sleep'	2.00 ± 2.51	1.42 ± 1.61	1.71 ± 1.25	2.28 ± 2.21
'No Sleep'	2.14 ± 2.03	1.57 ± 0.97	1.28 ± 1.97	12.14 ± 8.55
PVT: Mean Reaction Time				
'Sleep'	299.28 ± 21.53	286.00 ± 17.54	299.00 ± 22.23	300.71 ± 25.13
'No Sleep'	290.14 ± 25.24	303.28 ± 32.90	283.28 ± 28.42	352.71 ± 42.00
Stroop Test: Control				
'Sleep'	610.88 ± 57.73	642.94 ± 33.65	568.40 ± 31.69	618.97 ± 55.26
'No Sleep'	632.62 ± 57.91	617.49 ± 64.63	601.10 ± 61.64	652.01 ± 48.35
Stroop Test: Congruent				
'Sleep'	618.85 ± 62.29	600.09 ± 41.34	564.11 ± 62.83	589.05 ± 35.95
'No Sleep'	621.59 ± 41.67	581.51 ± 38.83	583.51 ± 56.26	606.16 ± 83.95
Stroop Test: Incongruent				
'Sleep'	701.61 ± 76.45	682.88 ± 79.77	594.35 ± 34.07	669.52 ± 53.43
'No Sleep'	689.34 ± 65.96	643.81 ± 41.46	666.71 ± 55.00	757.45 ± 58.48
Auditory Digit Span Forwards				
'Sleep'	9.28 ± 0.75	9.00 ± 0.81	9.00 ± 1.41	9.28 ± 1.38
'No Sleep'	9.00 ± 1.41	9.42 ± 1.13	9.85 ± 1.57	8.85 ± 1.46
Auditory Digit Span Backwards				
'Sleep'	8.71 ± 1.60	8.28 ± 1.38	8.28 ± 1.38	8.71 ± 1.11
'No Sleep'	8.71 ± 0.95	8.71 ± 1.38	8.42 ± 1.81	8.42 ± 1.81
Auditory Digit Span Difference (z-score)				
'Sleep'	0.00 ± 1.25	0.00 ± 1.18	0.00 ± 0.79	0.00 ± 1.20
'No Sleep'	0.00 ± 1.22	0.00 ± 1.17	0.00 ± 0.56	0.00 ± 1.09
Overall Situation Awareness				
'Sleep'	24.85 ± 2.26	24.14 ± 4.09	25.00 ± 4.39	25.57 ± 5.85
'No Sleep'	22.71 ± 6.84	24.85 ± 5.95	24.85 ± 4.98	23.71 ± 5.25
GPB: Dominant Hand				
'Sleep'	60.00 ± 7.48	54.57 ± 5.53	57.28 ± 5.05	53.85 ± 4.59
'No Sleep'	56.71 ± 4.57	55.85 ± 3.93	54.71 ± 2.69	60.28 ± 3.86
GPB: Non-Dominant Hand				
'Sleep'	62.28 ± 6.31	60.28 ± 7.06	60.14 ± 8.55	61.57 ± 9.71
'No Sleep'	62.14 ± 6.91	61.57 ± 9.21	59.71 ± 7.34	63.00 ± 8.56

PVT: Lapses in Attention = Psychomotor Vigilance Task: Lapses in Attention; PVT: Mean Reaction Time = Psychomotor Vigilance Task: Mean Reaction Time; SART = Situation Awareness Rating Technique; GPB: Dominant Hand – Grooved Pegboard: Dominant Hand; GPB: Non-Dominant Hand – Grooved Pegboard: Non-Dominant Hand.

Appendix I: Plain Language Statement (Study 4)

DUBLIN CITY UNIVERSITY
PLAIN LANGUAGE STATEMENT

The effects of acute sleep deprivation on pilots' mood, physiological arousal, pilot-specific skills and flying performance

School of Health and Human Performance, DCU

Anna Donnla O'Hagan (anna.ohagan3@mail.dcu.ie), Dr. Johann Issartel (johann.issartel@dcu.ie) and Dr. Giles Warrington (giles.warrington@dcu.ie)

Details of what involvement in the Research Study will require

This project will involve presenting at Dublin City University research laboratories on three separate occasions (1. Screening and Habituation; 2. Baseline Testing; 3. 24-Hr Sleep Deprivation Testing). During these testing periods you will be required to perform a series of tests which will measure your psychological function, physiological arousal, pilot-specific skills and flying performance.

During baseline testing, you will be required to arrive at the laboratories in the morning in a fully rested state. You will be required to perform a battery of psychological and neuro-cognitive tests. Each testing session is 60 minutes in duration. You will also be required to perform a 45-minute flight task on a computer-based flight simulator. During the 24-hour sleep deprivation period, you will be required to remain awake for 24 hours in the laboratory and perform the battery of psychological and neuro-cognitive tests at five separate time points throughout the testing period. Following testing sessions 1, 3 and 5 you will also be required to perform the flight task. Flight task performances will be video-recorded in order to allow for comparisons with the simulator output.

Body temperature (recording taken from the ear), blood pressure, heart rate and a saliva sample will be collected during each of the testing sessions. Additionally, a venous blood sample will be taken from the arm at the beginning and end of the baseline and 24-hour testing periods (eight blood samples in total).

Potential risks to participants from involvement in the Research Study (if greater than that encountered in everyday life)

There are very limited risks identified with involvement in this study. With the drawing of blood for testing there is always a chance of swelling and bruising after the test is completed. Blood will be sampled from a venous (arm)) site. The venous sample will be collected by a person trained in venopuncture.

Benefits (direct or indirect) to participants from involvement in the Research Study

Data from these studies will help you identify and become aware of the effects of fatigue, implemented via a bout of sleep deprivation, on your mood, physiological arousal, pilot-specific skills and flying performance on a computer-based flight simulator. Such information may help to inform your decisions and actions in relation to sleep and fatigue in your personal and working life.

Advice as to arrangements to be made to protect confidentiality of data, including that confidentiality of information provided is subject to legal limitations

All data and video recordings will be kept in the strictest of confidence with access being limited to the investigators, Anna Donnla O'Hagan, Dr. Johann Issartel and Dr. Giles Warrington. In accordance with DCU policy all data will be kept on-site in DCU in a locked secure area.

Advice as to whether or not data is to be destroyed after a minimum period

After a 5 year period, if participants do not wish to have their data returned, or do not contact the investigators, all data will be destroyed in accordance with DCU policy.

Statement that involvement in the Research Study is voluntary

If at any point during your participation in the study you feel as if you wish to leave, this is not a problem. You are under no obligation to stay involved if you do not wish too. Please make sure to contact the investigators if you are unable or unwilling to continue in the project so we can address any issues within the project.

If participants have concerns about this study and wish to contact an independent person, please contact:

The Secretary, Dublin City University Research Ethics Committee, c/o Research and Innovation Support, Dublin City University, Dublin 9. Tel 01-7008000

Appendix J: Informed Consent (Study 4)

DUBLIN CITY UNIVERSITY
INFORMED CONSENT

The effects of acute sleep deprivation on pilots' mood, physiological arousal, pilot-specific skills and flying performance

Principal Investigator: Ms. Anna Donnla O'Hagan, Dr. Johann Issartel & Dr. Giles Warrington

Other Investigators: Mr. Aidan Wall, Ms. Sarah Redmond & Ms. Talissa Walsh

Fatigue originates in the brain (e.g. when sleep pressure is increased) and impacts behaviour (e.g. decreases vigilance) which can enhance the occurrence of an adverse event. The purpose of this study is to analyse and evaluate the effect of fatigue, implemented via a bout of acute sleep deprivation on commercial airline pilots' mood, physiological arousal, pilot-specific skills and flying performance.

This project will involve presenting at Dublin City University research laboratories on three separate occasions (1. Screening and Habituation; 2. Baseline Testing; 3. 24-Hr Sleep Deprivation Testing). You will be required to perform a battery of psychological and neuro-cognitive tests. Each testing session is 60 minutes in duration. You will also be required to perform a 45-minute flight task on a computer-based flight simulator. During the 24-hour sleep deprivation period, you will be required to remain awake for 24 hours in the laboratory and perform the battery of psychological and neuro-cognitive tests at five separate time points throughout the testing period. Following testing sessions 1, 3 and 5 you will also be required to perform the flight task. Flight task performances will be video-recorded in order to allow for comparisons with the simulator output.

Body temperature (recording taken from the ear), blood pressure, heart rate and a saliva sample will be collected during each of the testing sessions. Additionally, a venous blood sample will be taken from the arm at the beginning and end of the baseline and 24-hour testing periods (eight blood samples in total).

<u>Participant – please complete the following (Circle Yes or No for each question)</u>
I have read the Plain Language Statement (or had it read to me) *Yes / No*
I understand the information provided *Yes / No*
I have had an opportunity to ask questions and discuss this study *Yes / No*
I have received satisfactory answers to all my questions *Yes / No*

If at any point during your participation in the study you feel as if you wish to leave, this is not a problem. You are under no obligation to stay involved if you do not wish to. Please make sure to contact the investigators if you are unable or unwilling to continue in the project so we can address any issues within the project.

Dublin City University will protect all the information about me, and my part in this study. I will be assigned a unique ID number under which all my personal information will be stored securely and saved in a password protected file in a computer at DCU. My identity or personal information will not be revealed or published. All records associated with my participation in the study will be subject to the usual confidentiality standards applicable to medical records. All contact information will be securely stored in Dublin City University and will not be revealed to any third party. In addition, the study findings may be presented at scientific meetings and published in a scientific journal but my identity will not be divulged and only presented as part of a group. I am aware that the confidentiality of information provided can only be protected within the limitations of the law. It is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions.

If I have questions about the research project, I am free to call Anna Donnla O'Hagan on 087 9433330 or Dr. Johann Issartel on 01 700 7461.

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project:

Participants Signature: ______________________________

Name in Block Capitals: ______________________________

Witness: ______________________________

Date: ______________________________

Appendix K: Avionics Integration Research SIMulator (AIRSIM) (Study 4)

In Study 3 participants were required to fly a 32-minute flight profile on an Avionics Integration Research SIMulator (AIRSIM) (Groeneweg, 1998) as a determination of flying performance. The flight task was designed by the research team and various collaborators (e.g. commercial airline pilots, members of IALPA, researchers at the National Aerospace Laboratory) and was programmed to the AIRSIM by Mr. Jaap Groeneweg (see Graphic 1 & 2). The high fidelity, desktop research flight simulator consisted of an Airbus interface, of which all participants were familiar. Participants were required to manually operate the flight simulator for the duration of the flight task – i.e. dis-engagement of the auto-throttle and the auto-thrust. Participants utilised the flight director (on the left-hand side of their interface) to guide their direction.

The flight task required participants to fly a hold in airspace above Groening airport in Amsterdam of which no participants in this particular study would be familiar. Flying a hold is a fairly regular occurrence for a commercial airline pilot in their everyday duties. A hold is ultimately a manoeuvre designed to delay an aircraft which is already in flight while maintaining it within a specified airspace. A hold usually consists of a racetrack pattern with right-hand turns. It takes approximately 4 minutes to complete a hold (i.e., one minute for each 180 degree turn, and two one-minute straight ahead sections).

The task commenced mid-flight at 10,000ft, heading 090 degrees at 250 knots and did not include a landing. Participants were commanded to perform specific control or performance parameters regarding airspeed, heading, altitude and bank at various time points throughout the flight task. Participants were provided with the call signal 'Delta Charlie Uniform 135' whilst the air traffic controller was referred to as 'Groening Approach'. Flight commands and instructions were provided via air traffic controller voice recordings.

The flight task was sub-divided in to three sections with each consisting of three mid-flight SA questions regarding location, speed, heading, altitude and on static TCAS (Traffic Avoidance Collision System) pictures during the flight task. Following instruction from the air traffic controller regarding icy conditions at their destination, during Section 2 participants are required to fly the hold. Participants were also required to conduct mid-flight fuel calculations whilst flying the holding pattern.

The following shows the instruction and time of instruction to participants during the flight task:

Call Sign: Delta Charlie Uniform 135
ATC Sign: Groningen Approach

Once the participant indicates they are ready they will begin the flight task. The task will begin with the pilot flying at heading 270 degrees at 10,000ft, flying at 250 knots.

00:45 – "Delta Charlie Uniform 135: Groningen Approach: turn left heading 255 degrees at 250 knots"

04:30 (12.4 nm from Sipsa) – "Delta Charlie Uniform 135: Groningen Approach: be advised please due to icy conditions at Groningen, the airport is closed. On reaching Sipsa route direct to Veror. Expect one round of the hold at Veror"

05:00 – Show TCAS for 5 seconds

05:30 (7.9 nm from Sipsa) – Ask situation awareness questions

13:30 – Ask problem solving questions (hand Laminate 1) – "Delta Charlie Uniform 135 based on Veror A fuel, how long can you hold to land at destination?"

18:00 – Ask problem solving questions (hand Laminate 2) – "Delta Charlie Uniform 135 based on Veror B fuel, how long can you remain in the hold to land at Alternate 2?"

21:00 – "Delta Charlie Uniform 135: Groningen Approach: the runway is now open. You can route direct to Getsi and descend altitude 5,000ft on QNH 1009 hecto-pascals"

23:30 – Show TCAS for 5 seconds

24:00 (10.5 nm from Getsi) – Ask situation awareness questions

25:00 (5 nm from Getsi) – "Delta Charlie Uniform 135: Groningen Approach: at Getsi, turn right heading 030 degrees at 240 knots indicated please"

27:00 – *(once they have turned – roll wings level)* "Delta Charlie Uniform 135: Groningen Approach: descend altitude 4,000ft at 1,000ft per minute please QNH 1009 hecto-pascals"

28:00 – "Delta Charlie Uniform 135: Groningen Approach: descend altitude 3,000ft, turn right heading 100 degrees at 15 degrees angle of bank please"

28:30 – Show TCAS for 5 seconds

29:00 – Ask situation awareness questions

30:00 – "Delta Charlie Uniform 135: Groningen Approach: descend altitude 2,000ft at 1,000ft per minute turn right heading 110 degrees and reduce speed 220 knots indicated please"

Once participant levels off (after 2 minutes), the task will be terminated.

Graphic 1.

Graphic 2.