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Factors contributing to the risk of airline pilot fatigue

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ABSTRACT

Fatigue is important in the aviation field because it affects many people's safety. The purpose of this study is to identify factors that affect airline pilot fatigue. This study proposes a fatigue model for airline pilots. Fatigue is classified into physical decline, mental decline, and rest defects. Based on 929 responses from pilots, this study verifies that pilot fatigue is affected by seven independent variables – flight direction, crew scheduling, partnership, aircraft environment, job assignment, ethnic difference, and hotel environment. Results show these factors affect physical fatigue, mental decline, and rest defects. These findings can contribute to reducing pilot fatigue, which is important in aviation in terms of physical fatigue, mental decline, and rest defects.

1. Introduction

Fatigue is a common sensation that is caused by a variety of activities associated with daily life (Curnow, 2002). Reports suggest that some 20% of the total working population is fatigued (Pawlikowska et al., 1994), and about 10% of men and 15% of women claim to be very tired or exhausted (Blackwell, 2010). When a driver is fatigued and/or stressed, the potential for a fatal accident increases because the driver fails to gather essential traffic environment information, which leads to poor decisions in traffic, a reduction in driving skill, and poor vehicle positioning on the road (I. D. Brown, 1993). The aviation industry is likewise affected by fatigue. One of the most frequently cited performance impairments is fatigue, and this has been a primary concern for the National Transportation Safety Board (NTSB) for over 40 years (FAA, 2012). More than 70% of aviation accidents can be attributed to human factors, which are recognized as one of the key determinants for managing and improving flight safety (Rudari et al., 2016; Yen et al., 2009).

In aviation workplaces, there are many factors that may result in fatigue, including social and family factors, and, in the case of transmeridian airline pilots, time zone changes (Caldwell, 2004). In view of the fact that sleep and circadian processes interact to influence sleep propensity, waking alertness, and performance, it is essential to accurately quantify the impact of these factors (Dongen and Dinges, 2000). Prolonged periods of working and displaced work schedules result in both subjective and physiological fatigue, cognitive performance decrements and errors, and safety risks (Mallis et al., 2004).

Pilots who flied regularly into their discretion hours had lower physical and psychological health, overall fatigue scores, and poorer self-rated general health. Seventy-five percent of 162 pilots reported severe fatigue (Jackson and Earl, 2006). A current study shows that the prevalence of sleep complaints was 34.9%, daytime sleepiness 59.3% and fatigue 90.6% (Reis et al., 2016).

Sleep is a major factor that determines fatigue. However, current technological advancements and the global economy require optimal human functioning 24 h a day, seven days a week. Throughout industrialized countries, a growing number of sectors (e.g. businesses, transportation, energy, public health, safety, and maintenance) now operate 24/7. For the millions of people working in these environments, the timing of sleep often deviates from its biologically natural nocturnal placement (Mallis et al., 2004). Most scientists believe that pilots should have the opportunity for 8 h of sleep in a rest period (NASA, 1999). However in many places, the current regulations do not ensure the opportunity for this amount of sleep. Pilots have filed reports with the National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System that also document the effects that work patterns have on pilot fatigue and performance (NASA, 1999). There is a frequent demand for airline pilots to maintain appropriate levels of alertness and performance when sleep is either reduced or misaligned relative to the endogenous circadian nadir for alertness (Sallinen et al., 2017).

There are active movements to manage the fatigue of airline pilots worldwide. The International Civil Aviation Organization (ICAO) published the second edition of its fatigue risk management manual, entitled *The Manual for the Oversight of Fatigue Management Approaches* (ICAO, 2016), and the American government published its rules in

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Flight and Duty Limitations and Rest Requirements: Flight Crew Members (FAR 117) (FAA, 2014). The EU 83/2014 Law was addressed pilot and cabin crew fatigue-related regulations; it was published in 2014 and implemented from February 18, 2016 (European_Commission, 2014). There are many task forces working to reduce pilot fatigue in many countries and organizations, including ICAO, the International Air Transport Association (IATA), and the International Federation of Air Line Pilots' Associations (IFALPA).

Analyses on fatigue causal factors have focused on medical and health factors rather than on cultural, humanities, and social systematic factors. Accordingly, this research focuses on determining fatigue causal factors from all perspectives.

2. Literature review

2.1. General theories on fatigue

Fatigue, its causes, mechanisms, and consequences have long been the topic of discourse and study. In lay terms, fatigue is readily understood as an outcome state in which one feels tired or sleepy. There is much debate between and within the many involved disciplines, but no definition has yet been agreed upon (Noy et al., 2011). Despite its importance to health and safety, there is a long history of disagreement on how to operationalize fatigue when studying exertion in human transport operators (Phillips, 2015).

Fatigue is defined as a suboptimal psychophysiological condition caused by exertion. The degree and dimension of the condition depend on the form and context of exertion. The fatigue changes strategies or resource use (Phillips, 2015). The Oxford dictionary defines fatigue as extreme tiredness resulting from mental or physical exertion or illness (Oxford, 2013). NASA defines it as feeling tired, sleepy, or exhausted (NASA, 1999).

In addition to the definitions listed in Table 1, there are two other important definitions of fatigue in the aviation field. First, ICAO defines fatigue as a physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness, circadian phase, or workload (mental and/or physical activity) that can impair a crew member's alertness and ability to safely operate an aircraft or perform safety-related duties (ICAO, 2010). Second, fatigue involves psychological and physical tiredness with a range of symptoms such as tired eyes, yawning and increased blink rate. Fatigue has major implications for workplace and transportation safety, and it is a negative symptom of many acute and chronic illnesses (Tran et al., 2010) (see Table 2).

2.2. Fatigue types

2.2.1. Physical fatigue

Fatigue is generally classified as either physical or mental. Sufficient rest is the only remedy for fatigue (Dinges et al., 1996) and an insufficient rest period does not enable a fatigued individual to recover from that fatigue (Dawson and McCulloch, 2005). From the viewpoint of airline pilots, fatigue is related to crew schedules and rest periods.

Physical fatigue is caused by more than just one muscle being unable to perform. During physical activity, the onset of muscle fatigue is gradual and depends upon an individual's level of physical fitness, and other factors, including sleep deprivation and overall level of healthiness. Proper rest can reverse this process. A lack of energy in the muscles causes the physical fatigue by reducing the drive originating from the central nervous system or by decreasing the efficiency of the neuromuscular junction (Wesensten et al., 2004).

2.2.2. Mental fatigue

Mental fatigue is a psychobiological state caused by prolonged periods of demanding cognitive activity and characterized by subjective feelings of tiredness and lack of energy (Marcora et al., 2008). It is measured as a reduction in the ability to perform mental tasks. Sleep disruptions, which may induce mental fatigue, decrease cognitive functioning and psychomotor vigilance task (PVT) performance. It is remarkably difficult to understand mental fatigue and the cognitive processes underlying its behavioral manifestations (Curnow, 2002).

Mental fatigue is also defined as a temporary inability to maintain optimal cognitive performance. During any cognitive activity, the symptom of mental fatigue is gradual and depends on an individual's cognitive ability, and also upon other factors, including sleep deprivation and overall health. Decreased physical performance has also been

Table 1
Definitions of fatigue.

Category	Definition	Source
Subjective	subjectively experienced disinclination to continue performing the task because of perceived reductions in efficiency	(Brown, 1995; Soames-Job and Dalziel, 2000)
	an overwhelming sense of tiredness, lack of energy and a feeling of exhaustion, associated with impaired physical and/or cognitive functioning	(Shen et al., 2006)
	Awareness of a decreased capacity for physical and/or mental activity due to imbalance in the availability, use and/or restoration of resources needed to perform an activity	(Strober and Deluca, 2013)
Physiological	the state of an organism's muscles, viscera, or CNS, in which prior physical activity and/or mental processing, in the absence of sufficient rest, results in insufficient cellular capacity or system-wide energy to maintain the original level of activity and/or processing by using normal resources	(Soames-Job and Dalziel, 2000)
	weakness … from repeated exertion or a decreased response of cells, tissues, or organs after excessive stimulation, stress or activity	(Hirshkowitz, 2013)
	a change in psychophysiological state due to sustained performance [of one or more tasks at work]	(Linden et al., 2003)
physiological/performance	reduced force production, loss of exercise capacity, increased sense of effort or perception of force	(Strober and Deluca, 2013)
	the inability to function at the desired level due to incomplete recovery from demands of prior work and other waking activities	(Gander et al., 2011)
Performance	measurable decrements in performance of an activity caused by extended time performing it	(Bartlett, 1953)
	a diminished capacity for work and possibly decrements in attention, perception, decision making and skill performance	(Cercarelli and Ryan, 1996)
	decrements in performance on tasks requiring alertness and the manipulation and retrieval of information stored in the memory	(Gawron et al., 2000)
Multiple	three aspects to fatigue: physiological, objective (work decrement), and subjective fatigue	(Bills, 1934)
	an individual's multi-dimensional physiological-cognitive state associated with stimulus repetition which results in a prolonged residence beyond a zone of performance comfort	(Hancock and Verwey, 1997)
	a psychophysiological state that occurs when a person is driving and feeling tired or drowsy, to the extent that they have reduced capacity to function, resulting in performance decrements and negative emotions and boredom as they attempt to stay awake during the task	(Craig et al., 2011)

Table 2
Pilot interview results.

Categories	Pilot fatigue factors
Flight direction	- Long distance flights heading east (west), which induce longer time differences - Sequenced opposite-direction flights heading east (west) with short rest periods
Crew scheduling	- Improper scheduling systems (without participation from pilots) - Early departure flights (requiring pilots to wake up before 5 am at their home base) and short layover flights (only 24-h breaks at the layover hotel, which changes the sleeping pattern and prohibits sleep before flight) - Two captains and one flight officer on a two-leg flight (three pilots flying multi-leg flights, which induces more fatigue than two sets of pilots (four pilots)) - Unreasonable laws regarding flight time restrictions - Multiple short-haul flights causing more fatigue, but with the same regulations as long-haul flights
Partnership	- Different backgrounded crew pairings - Flying with administrative crew members (fatigue from bureaucracy) - Flying with significantly older or younger pilots (fatigue from multi-generational hierarchy)
Aircraft environment	- Dryness - Noise - Lighting during rest - Cosmic rays in polar flights
Job assignment	- Unreasonable policies for job assignments - Multi-leg flying (flying more than four multi-legs a day (too many multi-leg flights at once) - Night flights (long-haul flights with take-offs and landings at night, long-haul flights with one crew, quick turnaround night-flights, and multi-leg night flights) - Long periods of duty flight work - Short breaks at international layover stations - Specific fatigue-inducing flight patterns (long-haul flights for two nights and three days, dawn arrivals, 24-h breaks with night departures for long-haul flights) - Frequent schedule changes - Insufficient rest periods - Irrational work rules for standby and reserve work - Unofficial work
Ethnic differences	- Different duty styles and rest time splits when flying with foreign crews
Hotel environment	- Quality of layover hotels (hotels that hinder rest periods) - Inconvenient hotel facilities - Poor hotel environment (noisy hotel locations, inconvenient access to the restaurants)
Others	- Poor aircraft management and vulnerable airports - Increases in standard operating procedures (SOPs) and callouts - Extensive amounts of verbal exchange briefings during flights - Excessive flight safety instructions from the transport ministry safety director - Difficulty in sleeping the night prior to a flight - Biorhythm, improper briefing room location and environment, and demoralization of flight crew - Minimal rest periods, improper company systems, bad weather, aircraft defects, noncooperative cabin crews, complicated airports, coordination with control centers in abnormal situations, airport delays, poor airport facilities

shown in mental fatigue. It can manifest as somnolence, lethargy, or directed attention fatigue. It is believed that the brain's reticular activating system modulates the perception of mental fatigue.

2.3. Pilot fatigue

Fatigue is a significant risk factor in workplace accidents and fatalities (Dawson et al., 2013; Drongelen et al., 2016) in a wide range of settings, with the implication that tired people are less likely to produce safe performance and actions. These settings include transportation sectors such as road, aviation, rail, and maritime, as well as other occupational settings, including hospitals, emergency operations, and law enforcement, particularly when irregular hours of work are involved (Mitler et al., 1988). This is because tired people are less likely to produce safe performance and actions (Williamson et al., 2009). Almost everyone becomes fatigued now and again, either at work or during their leisure time, and at these times, people may be at increased risk of accident or injury. Fatigue effects such as lowered response times and the failure to pay attention or suppress inappropriate strategies have been identified in many high profile accidents (Mitler et al., 1988).

In the aviation industry, light fatigue alone might be an important contributor to a large number of aviation accidents, although it is difficult with the current accident investigation process to identify whether or not fatigue is the cause of the associated accident (Yen et al., 2009). Fatigue, sleep loss, and circadian disruption created by flight operations can degrade performance, alertness, and safety. Important physiological information about the human operator can be used to guide operations and policy. The aviation industry needs to meet the challenge of managing fatigue in flight operations (Goode, 2003). Since 1990, the NTSB has acknowledged fatigue as a major risk to safety and performance. For over 40 years, the NTSB has frequently cited fatigue as an important concern (Hartzler, 2013).

More than 70% of aviation accidents can be attributed to human factors, and pilot fatigue is now recognized as one of the key determinants for managing and improving flight safety. However, fatigue is often an under-reported problem in both civilian and military aviation operations. Fatigue is involved in at least 4–8% of aviation mishaps, and surveys of pilots and aircrew members reveal that fatigue is an important concern throughout flight operations (Caldwell, 2004). The majority of duty times and rest rules are associated with working hour limitations, while 37% are associated with sleep and rest requirements, and 6% with circadian rhythm (Banks et al., 2012). In addition, from 1994 to 1998, there were 227 schedule-related fatigue incidents reported by pilots, or approximately 45 per year (NASA, 1999). Fatigue is recognized as a factor that directly led to the Guantanamo Bay accident in 1993 (National_Transportation_Safety_Board_(NTSB), 1994) and the Little Rock accident in 1999 (Goode, 2003).

It has been demonstrated that fatigue, sleep-loss, and circadian disruption due to flight operations can affect both crew performance and flight safety (Rosekind et al., 1997). The detrimental effects of fatigue in aviation are well established, as evidenced by both the number of fatigue-related mishaps and numerous studies which have found that most pilots experience a deterioration in cognitive performance as well as increased stress during the course of a flight (Hartzler, 2013).

2.4. Fatigue factors

What are the causal factors of fatigue? Independent variables include medications, restorative napping, illicit drugs, alcohol, education, social class, income, partner/marital status, dependency care, meal timing and content, ambient heat/cold/noise/light/chemicals, time since last sleep, physical workload for work motivation, working arrangements, shift start time and duration, work recovery time, commute type, job tenure/job control/job reward/monotony, second jobs, and job/non-job stress. Dependent variables include physical health, mental health, sleep needs, sleep debt, circadian phase, circadian time structure, circadian desynchrony, chronotype, endurance, genetics, age, sex, race, nutritional status, BMI, and personality traits (Milia et al., 2009; Wu et al., 2016).

In the marine industry, the most common causes of fatigue known to seafarers are lack of sleep, poor quality of rest, stress and excessive workloads. Each varies depending on the circumstances, including operational and environmental factors. There are many ways to categorize the causes of fatigue. To ensure thoroughness and to provide good coverage of most causes, they have been categorized into four general factors – crew-specific factors, management factors (ashore and aboard ship), ship-specific factors, and environmental factors (IMO, 2001).

The major causes of fatigue, including sleep homeostasis factors, circadian influences, and the nature of the task effects and safety outcomes can be linked to accidents and injuries as well as adverse effects on performance. In the transportation sector, the responsibility for fatigue risk management can be identified at three levels – regulatory responsibility, industry/company responsibility, and individual responsibility (Gander et al., 2009).

In the manual for the oversight of fatigue management approaches, fatigue factors are categorized into legal framework, commercial pressure, staff arrangements, staff demographics, acceptance of shared responsibilities for fatigue management, fatigue management structure, geographical location, level of isolation of professional during duty period, working condition, irregular operation, workload, interaction with other aviation professionals, experience level, and lifestyle influences (ICAO, 2016).

2.5. Fatigue risk management system

The impact of fatigue is often underappreciated, but many of its deleterious effects have long been known. Lindberg recognized the detrimental consequences of long duty hours (and long periods of wakefulness) on fight performance back in the 1920s, and scientists began to appreciate the negative impact of rapid time zone transitions in the early 1930s. Such knowledge was no doubt pivotal to the formulation of regulations such as the Civil Aeronautics Act of 1938, designed to manage aircrew duty hours and flight times (Caldwell, 2004).

However, there have been few changes to aircrew scheduling provisions and flight-time limitations since they were first introduced. Although the scientific understanding of fatigue, sleep, shift work, and circadian physiology has advanced significantly over the past several decades, current regulations and industry practices have in large part failed to adequately incorporate the new knowledge (Dinges et al., 1996).

There are various approaches to fatigue risk management. New flight regulations and flight time limitations (FTLs) have been implemented by the Federal Aviation Administration (FAA) and EASA. Training and education have been conducted with flight crew for fatigue risk management to integrate scientific knowledge into the FTLs (Cabona et al., 2011). Even after years of recognizing the physical and cognitive impairments associated with fatigue due to sleep debt, as well as numerous improvements in available countermeasures, fatigue remains one of the primary physiologic factors implicated in aviation mishaps and general mistakes made by aircrews (Drury et al., 2012).

ICAO defines a Fatigue Risk Management System (FRMS) as “[a] data-driven means of continuously monitoring and managing fatigue-related safety risks, based upon scientific principles and knowledge as well as operational experience that aims to ensure relevant personnel are performing at adequate levels of alertness” (ICAO, 2010). FAA defines an FRMS as follows. “Fatigue risk management systems (FRMS) mean a management system for a certificate holder to use to mitigate the effects of fatigue in its particular operations. It is a data-driven process and a systematic method used to continuously monitor and manage safety risks associated with fatigue-related error” (FAA, 2014).

An FRMS aims to ensure that flight and cabin crew members are sufficiently alert so they can operate to a satisfactory level of performance. The traditional regulatory approach to managing crew member fatigue has been to prescribe limits on maximum daily, monthly and yearly flight and duty hours, and require minimum breaks within and between duty periods. This approach comes from a long history of limits on working hours dating back to the industrial revolution. Prescriptive flight and duty time limits represent a somewhat simplistic view of safety — being inside the limits is safe while being outside the limits is unsafe — and they represent a single defensive strategy. While they are adequate for some types of operations, they are a one-size-fits-all approach that does not take into account operational differences or differences among crew members (ICAO, 2012).

Economies rely on transportation systems that operate well beyond normal working hours to convey people and freight to meet personal and business needs. However, the around-the-clock operational requirements of transport systems may exceed the human capacity to work efficiently and safely. This inability to optimally perform around the clock is typically attributed to fatigue that results from sleep homeostasis, circadian rhythms, and workload. An FRMS employs multilayered defensive strategies to manage fatigue-related risks regardless of their source. It includes data-driven, ongoing adaptive processes that can identify fatigue hazards and then develop, implement and evaluate controls and mitigation strategies. These include both organizational and personal mitigation strategies. While an FRMS is based on scientific principles, its application within various aviation contexts requires operational experience and knowledge. It needs to be developed, understood and managed by people who have comprehensive experience in the complex operational environment. Various data analyses can be meaningfully interpreted taking into consideration particular contexts, and workable operational strategies can be developed (ICAO, 2012). The evolution of regulatory frameworks is traced, from uni-dimensional hours of service regulations through to frameworks that enable multi-dimensional FRMS. These regulatory changes reflect advances in understanding of human error in the aetiology of accidents, and in fatigue and safety science. FRMS implementation shifts the locus of responsibility for safety away from the regulator towards companies and individuals, and requires changes in traditional roles (Gander et al., 2009).

The FRMS concept entered the transportation sector in the early 21st century in a series of regulations that limited working hours in rail, road and aviation operations. The approach reflects an early understanding that long unbroken periods of work could produce time-on-task fatigue, and that sufficient time was needed to recover from work demands and to attend to non-work aspects of life. Scientific evidence began accumulating that implicated other causes of fatigue in addition to time-on-task, particularly in 24/7 operations. The most significant new concerns are the early morning departures after short/medium flights to restore and maintain all aspects of waking functions and daily rhythms in the ability to perform mental and physical work. Also of concern is sleep propensity (the ability to fall asleep and stay asleep), which is driven by the daily cycle of the circadian biological clock in the brain. This new knowledge is particularly relevant in the aviation industry, which is unique in combining 24/7 operations with trans-meridian flight (IFALPA and ICAO, 2011).

3. Pilot fatigue model

3.1. Pilot interview

Based on the literature review, actual airline pilot interviews were conducted to elicit practical experience and opinions. A 17-item (open-ended question) interview was employed. The interviews were conducted with 20 representatives of two major airline pilot unions in Korea, all of whom were captains or first officers with long-as well as short-haul flight experience.

3.2. Research model

The literature review and the pilot interviews show that many factors affect airline pilot fatigue. With a mix of fatigue categories from previous research, seven independent variables and three dependent variables are derived for the hypotheses.

3.3. Hypotheses

3.3.1. Flight direction

Jet lag is associated with major body function problems such as sleepiness, hunger, and bowel movements, and a longer time for readjustments is required after westward flights. In addition, after flying east, it is more difficult to sleep. This phenomenon might lead to errors committed by pilots and business professionals. The probable association between errors (or accidents) and jet lag has led to suggestions that there exists a causal link between the two (Arendt and Marks, 1982). The severity of jet lag symptoms depends on the direction of travel (east or west) and number of time zones crossed (Drury et al., 2012). After flying east across six or more time zones, the circadian body clock may adapt by shifting in the opposite direction, for example shifting 18 time zones west rather than six time zones east. When this happens some rhythms shift eastward and others westward and adaptation can be particularly slow (ICAO, 2016). In the interviews, the pilots suggested that flying west caused more fatigue than flying east.

Hypothesis 1a. The flight direction in a long-haul flight has a positive effect on pilot fatigue, which causes physical fatigue.

Hypothesis 1b. The flight direction in a long-haul flight has a positive effect on pilot fatigue, which causes mental fatigue.

Hypothesis 1c. The flight direction in a long-haul flight has a positive effect on pilot fatigue, which causes a lack of rest.

3.3.2. Crew scheduling

Airline pilots are tired due to their work schedules, with frequent changes in duty schedules, early morning starts, and extended duty periods. It is critical that fatigue countermeasures be available to help combat the often overwhelming effects of sleep loss or sleep disruption (Hartzler, 2013). Pilot schedules impact pilot performance and safety risk. For example, one can look at pilot work variables to see how they affect crew member alertness, how alertness affects crew performance under differing workloads and operational environments, and how pilot work variables and alertness combine to affect safety performance, which is measured in terms of accidents and incidents. There is a complex relationship between scheduling and performance (Goode, 2003). The sleep loss, sustained wakefulness, and circadian disruption associated with such schedules mean that long-haul pilots are likely to experience elevated levels of fatigue during some flights (Petrilli et al., 2006).

Shift work can be a burden to workers due to disturbances in biological and social circadian rhythms, and can negatively affect health and performance in the short- and long-term. Short-term effects of shift work comprise reduced sleep length and decreased sleep quality (FAA, 2012). A shift schedule that minimizes circadian disruption and accumulation of sleep loss across a shift cycle, and concurrently permits adequate recovery during days off, will be beneficial for sleep and alertness (Ven et al., 2016).

However, when firms design work schedules, they prioritize reductions in total labor costs, and they seek to enhance operational flexibility and improve worker productivity and utilization. This drives firms to determine the right mix of jobs in each particular schedule. Moreover, in recent years, operational planning and management in transportation companies has become increasingly complex (Liao, 2015). As such, airline crew scheduling problems have been traditionally formulated as set covering problems or set partitioning problems. When flight networks are extended, these problems become more complicated and thus more difficult to solve (Yan and Tu, 2001). The construction of schedules (rosters) using scientific principles and operational knowledge is required (ICAO, 2016). In the interviews, the pilots asserted that the current scheduling system caused crew fatigue. They felt that this system consisted of unreasonable crew scheduling, unstable crew schedule operations, and irregular scheduling. Moreover, it did not include schedule bidding, and it did not take crew opinions into account.

Hypothesis 2a. Inadequate crew scheduling has a positive effect on pilot fatigue, which causes physical fatigue.

Hypothesis 2b. Inadequate crew scheduling has a positive effect on pilot fatigue, which causes mental fatigue.

Hypothesis 2c. Inadequate crew scheduling has a positive effect on pilot fatigue, which causes a lack of rest.

3.3.3. Partnership

In the airline planning processes used by major airlines, a set of anonymous crew members is paired so as to cover, at minimum cost, the flights scheduled to be operated by a given aircraft type over a whole month (Saddoune et al., 2010). However, the cultural values espoused by managers from different nations predispose them to prefer particular methods of handling issues that arise during teamwork. In most organizations, at least some of their employees work collaboratively with persons whose personal backgrounds differ from their own. Such cross-cultural and cross-national linkages may occur with individuals or with teams (Smith, 1999). However, when individual values are mixed in a single flight crew, the various crew members may experience difficulty in exchanging information and knowledge. This can affect flight safety, and furthermore, it can cause crew fatigue and accidents (Jeon, 2014). In the interviews, the pilots suggested that depending on their flight crew partners, and the type of partnership that was experienced, these cross-cultural and cross-national linkage played a role in fatigue. These partnerships do not affect fatigue as a result of a lack of rest because the interactions only occur during flights.

Hypothesis H3a. Unsuitable cross-cultural partnerships have a positive effect on pilot fatigue, which causes physical fatigue.

Hypothesis H3b. Unsuitable cross-cultural partnerships have a positive effect on pilot fatigue, which causes mental fatigue.

3.3.4. Aircraft environment

Noise (Dawson and McCulloch, 2005), vibrations through aircraft seats (Ciloglu et al., 2015), light (Avers and Johnson, 2011), aircraft illumination (Silva et al., 2013), air velocity, air temperature, humidity (Maier and Marggraf-Micheel, 2015), bumpy flights (Vink et al., 2012), and air pollution (Lee, 1996) have an effect on passengers and crew fatigue, as well as on comfort (ICAO, 2016).

Pilots use more physical strength because they are exposed to special physical environments, and they are exposed to various stresses. In addition pilots must continuously pay attention to the automatic digital instruments, requiring considerable focus and strain (Dawson et al., 2013).

In the interviews, the pilots indicated that aircraft noise and dryness affected their fatigue levels. These elements are all physical, so they affect physical fatigue, and they affect the pilots' ability to rest in the aircraft.

Hypothesis 4a. Inadequate aircraft environments have a positive effect on pilot fatigue, which causes physical fatigue.

Hypothesis 4c. Inadequate aircraft environments have a positive effect on pilot fatigue, which causes a lack of rest.

3.3.5. Job assignments

Manpower planning processes for airline workers are complex, multistage planning and control processes. However, determining the right mix of jobs in work schedules can improve worker productivity and utilization (Liao, 2015). For shift workers, early morning, sequenced shifting work schedules cause fatigue.

In aviation, fatigue is caused because pilots with long-haul flight schedules with multiple flight legs and layovers often experience a misalignment of the light/dark cycle and sleep/wake cycle (external circadian desynchrony) (Mallis et al., 2004). In addition, the most important influences on fatigue are the number of sectors and duty length. These are associated with fatigue in a linear fashion. The time of day has a weaker influence, with lower levels at midday and increased fatigue (Powell et al., 2007). Moreover, unpredictable work hours, long duty periods, circadian disruptions, and insufficient sleep are commonplace in airline flight operations and they affect pilot fatigue, which cause significant problems in modern aviation operations (Samel et al., 1995). Thus various job assignment factors affect crew fatigue and rest.

In the interviews, the pilots expressed the opinion that night flights, early morning flights, long duration night flights, quick turnaround night flights, multi-leg flights once, and insufficient augment crew members increased their fatigue.

Hypothesis 5a. Inadequate job assignments have a positive effect on pilot fatigue, which causes physical fatigue.

Hypothesis 5b. Inadequate job assignments have a positive effect on pilot fatigue, which causes mental fatigue.

Hypothesis 5c. Inadequate job assignments have a positive effect on pilot fatigue, which causes a lack of rest.

3.3.6. Ethnic differences

Sleep length and quality differs depending on racial and ethnic groups. Racial and ethnic differences in sleep are widely reported. Sleep characteristics also depend on national history and cultural differences (Yoon, 2015). Genetics can affect fatigue as an exogenous variable (Milia et al., 2009). Some races report more sleep complaints, difficulty maintaining sleep, and early-morning awakenings (Petrov and Lichstein, 2015).

Racial and ethnic differences in sleep duration are not well understood (Hale and Do, 2007) However, when employees of different races and ethnicities work together, differences in fatigue levels might result. In the interviews, the pilots said that flying with foreign crew members, who differed in terms of duty styles and rest patterns, affected their fatigue levels.

Hypothesis 6a. Ethnic differences have a positive effect on pilot fatigue, which causes physical fatigue.

Hypothesis 6b. Ethnic differences have a positive effect on pilot fatigue, which causes mental fatigue.

3.3.7. Hotel environment

Urban housing environments have received increasing attention as sites that can both contribute to health and produce harm (Knight et al., 2014). The sleep environment can affect sleep quality and result in pilot fatigue (ICAO, 2016; Rudari et al., 2016).

In the interviews, the pilots asserted that hotel environments that prevented sufficient rest, inconvenient hotel facilities, and short resting periods at hotels were causing fatigue. The hotel environment is related to physical rest. As such, mental fatigue is not related to this factor.

Hypothesis 7a. An improper hotel environment has a negative effect on pilot fatigue, which causes physical fatigue.

Hypothesis 7c. An improper hotel environment has a negative effect on pilot fatigue, which causes a lack of rest.

4. Methodology

The 82-item (primarily multiple-choice) survey was conducted online in May 2015 for two weeks using SurveyMonkey (www.surveymonkey.net). The survey items are presented in the Appendix. A total of 929 responses were received, represented approximately 19% of the estimated nationwide airline pilot population in Korea.

We sent each pilot a message for the online survey and called her or him to participate in this survey. Airline Pilots Association of Korea (ALPA-K) helped us in encouraging pilots participate in this survey. Almost all pilots are using smartphones. Pilots used their smartphones to participate in online survey during recess or off-duty. The high response rate for this survey shows that airline pilots have many hardships associated with fatigue.

Most of the respondents (83%) were pilots at major airlines, and the others worked for low cost carriers (17%). 63% of the respondents were first officers, while the remaining 37% were captains. 39% of the respondents flew short-haul flights, and 61% flew long-haul flights. 37% had less than 4000 h of flight time, while 63% had accumulated more than 4000 h 43% were under 39 years of age, while 57% were older than 39. Their participation was voluntary.

5. Results

5.1. Factor analysis

The data was checked to determine whether it satisfied the factor analysis assumptions. Three methods were used for the analysis: the correlation coefficient among question items, Bartlett's test of sphericity, and the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy. In addition, reliability was checked since it is the most common index of the validity of measures. In general, a reliability value of less than 0.60 is considered poor, the 0.70 range is considered acceptable, and 0.80 or over is considered good (Sekaran, 2003).

A factor analysis was used to check whether the scale items measured the construct in question or other constructs. Generally, a value of 0.70 or above is deemed acceptable (Fornell and Larcker, 1981). As Cronbach's alpha assesses how well the items in a set are positively correlated with one another, it was used to test the internal consistency (see Table 3).

As shown in Tables 4 and 5, all of the alpha values were greater than the recommended level and showed good reliability with Cronbach's alpha (> 0.80) in each construct. In this study, question items with a loading under 0.6 were cut off, and construct validity was examined using the Kaiser–Meyer–Olkin test and Bartlett's test of sphericity, which were subsequently used to assess the appropriateness of the correlation matrices for the factor analysis (Hair et al., 1998). The results of Bartlett's test of sphericity in this study showed Sig (P) = 0.000 ($\chi 2 = 18{,}794.369$, degree of freedom = 1431). Thus, the data satisfied the factor analysis assumption, and it showed evidence of construct validity.

Table 3
Demographics of survey participants.

Answer Options	Frequency	Response Percent
Age		
20–29 years old	9	1.0%
30–39years old	390	42.0%
40–49years old	432	46.5%
50–59years old	95	10.2%
60 or over	3	0.3%
Work Experience		
less than 1 year	9	1.0%
between 1 and 3 years	115	12.4%
between 3 and 5 years	126	13.6%
between 5 and 15 years	465	50.0%
between 15 and 20 years	126	13.6%
between 20 and 30 years	84	9.0%
more than 30 years	4	0.4%
Flight Time Accumulated		
less than 1000 h	26	2.8%
between 1000 and 4000 h	317	34.1%
between 4000 and 10,000 h	457	49.2%
between 10,000 and 20,000 h	117	12.6%
more than 20,000 h	9	1.0%
Position		
First officer trainee	1	0.1%
Short-haul first officer	177	19.0%
Long-haul first officer	410	44.1%
Short-haul captain	149	16.0%
Long-haul captain	193	20.8%
Administration adjunct pilot	15	1.6%
Fleet		
Short-haul fleet	363	39.1%
Long (middle)-haul fleet with various rest facilities	379	40.8%
Long-haul fleet with bunk rest facilities only	66	7.1%
Cargo or mainly cargo fleet	120	12.9%
Past Fleet		
Short-haul fleet	674	72.5%
Long (middle)-haul fleet with various rest facilities	316	34.0%
Long-haul fleet with bunk rest facilities only	13	1.4%
Cargo or mainly cargo fleet	190	20.4%
Short-haul fleet for first airliner	147	15.8%

5.2. Regression analysis

The proposed model and hypothesized paths were tested based on a regression analysis using SPSS (see Fig. 1). A multiple regression analysis was carried out in terms of physical fatigue, mental decline, and rest defects. In Figs. 2–4, the results derived from examining the relationship between fatigue factors and the fatigue classification are shown, and those of physical fatigue, mental fatigue and lack of rest are shown in Tables 6–8.

Fig. 2 shows the results of the multiple regression analysis on physical fatigue. First, flight direction, crew scheduling, partnership, aircraft environment, job assignment, and ethnic difference have significant positive effects on physical fatigue ($R^2 = 0.223$), and hotel environment has a significant negative effect on physical fatigue. Thus, the hypotheses related to physical fatigue are supported.

Fig. 3 shows the results of the multiple regression analysis on mental decline. First, flight direction, crew scheduling, partnership, job assignment, and ethnic difference have significant positive effects on mental fatigue ($R^2 = 0.174$). Thus, the hypotheses related to mental fatigue are supported.

Fig. 4 shows the results of the multiple regression analysis on lack of rest. First, flight direction, crew scheduling, aircraft environment, and job assignment have significant positive effects on lack of rest, and hotel environment has a significant negative effect on physical fatigue ($R^2 = 0.35$). Thus, hypotheses related to lack of rest are supported.

6. Conclusions

6.1. Conclusions

This research first carried out a broad review of the academic literature to determine the contributing factors to airline pilot fatigue. These factors were drawn from diverse fields, including ground transportation, maritime transportation, medicine, psychology, and safety science. Based on this literature review, pilot interviews were conducted to reflect actual experiences and opinions. On the basis of the literature research and interviews, hypotheses and survey questions were created, and a nationwide survey was conducted.

The results showed that seven major items increased pilot fatigue, which reduced flight operational performance. The seven items were inadequate schedule operations, different flight directions, incorrect partnerships resulting from culture, inadequate aircraft environments, inappropriate job assignments, ethnic differences, and inadequate hotel environments. Inherent pilot fatigue was also divided into three factors – physical fatigue, mental fatigue, and fatigue due to a lack of rest.

The seven fatigue factors can affect fatigue in different ways, and all of them can be related to other factors or work independently. Pilots are human beings, so a certain level of fatigue is unavoidable. However mitigating fatigue to a certain degree is required for flight safety. Improvements in any of the seven causal factors can lead to reductions in all three fatigue factors (i.e. physical fatigue, mental fatigue, and a lack of rest). In terms of addressing the seven causal factors, multiple organizational bodies can play a role, including government, airline company administrations, and pilots. All of these bodies should try to control the seven fatigue factors both independently and in conjunction with one another. In addition, this study can serve as a first step to developing a national or industrial fatigue risk management system.

The results of this study are expected to contribute to the regulatory agencies concerned with aviation safety or to the safety management sector of the airline. First of all, understanding exactly what the airline pilots' fatigue factors are could be an important element in aviation safety management. The results of this study are expected to be available for aviation related safety regulations or guidance, for instance FRMS.

6.2. Limitations and future research

This study attempted to recognize the factors attributing to fatigue among airline pilots. Fatigue risk management for airline pilots is essential to prevent aircraft accidents. Accordingly ICAO issued its Manual for the Oversight of Fatigue Management Approaches (second edition) in 2016. In this manual, most of the text discussing fatigue factors is related with sleep. This research can contribute pilot fatigue factors from various perspective.

However, several limitations must be noted. First, it is possible that alternative research methods might determine additional fatigue factors. In the pilot interviews, the pilots indicated many other factors not listed in this study that they felt contributed to fatigue. Moreover, this study did not determine that these additional factors were unrelated to the fatigue dependent factors. For example, many studies have pointed out that flying across time zones has an effect on pilot fatigue. In addition, the initial factor analysis in the present study determined that time zone-related factors were interconnected. However, the regression analysis did not indicate a relationship with fatigue.

Second, the extent to which pilots are experiencing fatigue should be measured. Third, after the two aforementioned points are researched, a final study on the management of pilot fatigue with respect to each fatigue factor should be carried out.

Third, there is a possibility that the process of online surveys failed to present clear criteria to respondents. The distinction between general and recent flight fatigue can be blurred. It is desirable to make this clearer in future studies.

Table 4
Results of factor analysis of independent variables.

	Component						
	Flight direction	Crew scheduling	Partnership	Aircraft environment	Job assignment	Hotel environment	Ethnic difference
FD1	**0.902**	-0.006	0.070	0.034	-0.023	-0.006	0.011
FD2	**0.894**	-0.004	0.071	0.001	0.007	-0.021	0.060
FD3	**0.893**	0.034	0.017	0.039	-0.015	-0.011	0.025
FD4	**0.861**	0.035	0.099	0.065	-0.018	0.007	0.080
FD5	**0.840**	0.019	0.011	0.062	0.037	0.039	0.019
FD6	**0.802**	-0.049	0.062	0.075	0.081	-0.096	0.246
FD7	**0.800**	-0.035	0.096	0.092	0.096	-0.106	0.217
CS1	-0.042	**0.778**	0.062	0.133	0.091	-0.093	-0.046
CS2	0.026	**0.757**	0.025	0.077	0.051	-0.098	0.018
CS3	-0.043	**0.723**	0.046	0.225	0.125	-0.102	0.048
CS4	0.041	**0.692**	0.072	0.133	0.178	-0.063	0.049
PS1	0.138	-0.064	**0.808**	0.073	0.086	-0.043	0.065
PS2	0.167	-0.031	**0.803**	0.060	0.143	-0.068	0.082
PS3	-0.018	0.144	**0.717**	0.103	-0.011	-0.046	0.067
PS4	0.052	0.133	**0.694**	0.057	-0.022	-0.001	0.139
AE1	0.111	0.145	0.069	**0.794**	0.000	-0.057	0.079
AE2	0.091	0.068	0.060	**0.767**	0.081	-0.051	0.004
AE3	0.049	0.165	0.050	**0.670**	0.136	-0.033	0.024
AE4	0.022	0.152	0.120	**0.666**	0.114	-0.116	-0.003
JA1	-0.001	0.067	0.029	0.103	**0.872**	0.008	0.071
JA2	0.183	0.120	0.110	0.088	**0.799**	0.012	-0.060
JA3	-0.075	0.233	0.024	0.116	**0.641**	-0.054	0.136
HE1	-0.046	-0.141	-0.072	-0.116	-0.012	**0.884**	0.011
HE2	-0.074	-0.160	-0.069	-0.124	-0.015	**0.868**	0.002
ED1	0.210	0.019	0.201	0.035	0.098	0.025	**0.839**
ED2	0.325	0.043	0.193	0.059	0.056	-0.007	**0.804**
Cronbach's alpha	0.947	0.803	0.785	0.759	0.695	0.815	0.796

Numbers in bold show loading coefficients for items in each construct.

Table 5
Results of factor analysis of dependent variables.

	Component		
	Physical fatigue	Metal fatigue	Lack of rest
PF1	**0.824**	0.279	0.084
PF2	**0.802**	0.282	0.083
PF3	**0.679**	0.116	0.269
PF4	**0.647**	0.436	0.102
PF5	**0.622**	0.112	0.342
MF1	0.147	**0.807**	0.213
MF2	0.245	**0.770**	0.087
MF3	0.248	**0.758**	0.115
MF4	0.455	**0.605**	0.197
LR1	0.144	0.055	**0.788**
LR2	0.110	0.294	**0.770**
LR3	0.270	-0.034	**0.728**
LR4	0.099	0.314	**0.615**
Cronbach's alpha	0.840	0.829	0.754

Numbers in bold show loading coefficients for items in each construct.

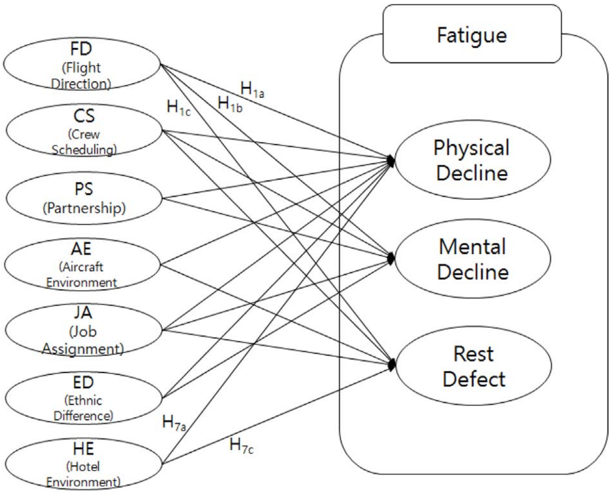

Fig. 1. Research model.

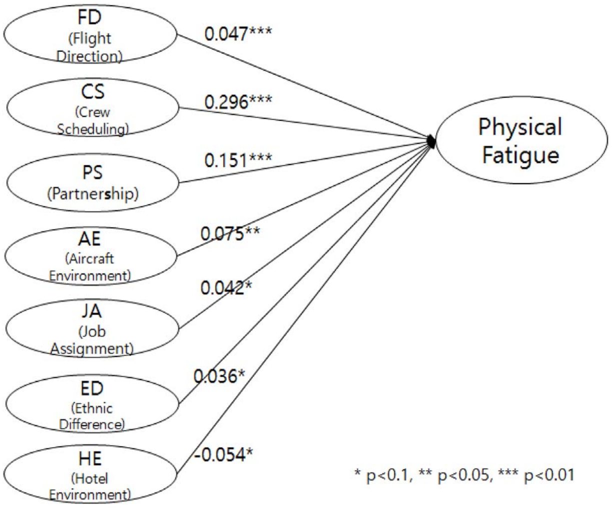

Fig. 2. Results of hypothesis testing (physical fatigue).

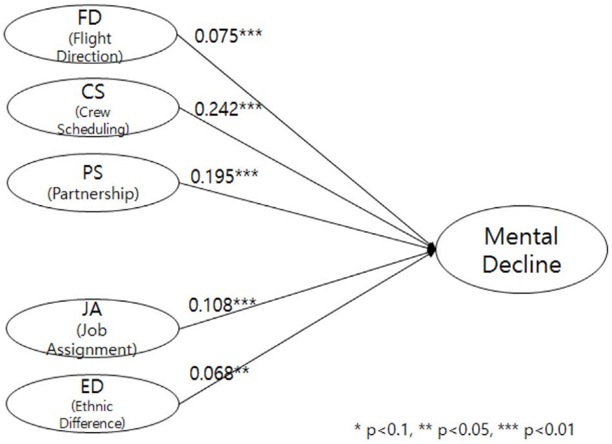

Fig. 3. Results of hypothesis testing (mental decline).

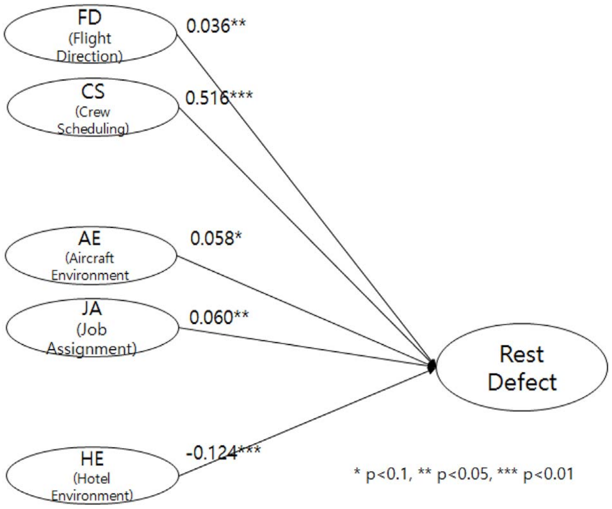

Fig. 4. Results of hypothesis testing (rest defects).

Table 6
Results of regression analysis (physical fatigue).

	coefficient	Standard error	Standardized coefficient	t	p-value
constant	0.699	0.224		3.127	.002
FD	**0.047**	0.017	0.097	2.700	**.007**
CS	**0.296**	0.043	0.259	6.866	**.000**
PS	**0.151**	0.030	0.179	5.018	**.000**
AE	**0.075**	0.036	0.077	2.085	**.037**
JA	**0.042**	0.025	0.059	1.663	**.097**
ED	**0.036**	0.021	0.064	1.694	**.091**
HE	**-0.054**	0.030	-0.062	−1.777	**.076**

Numbers in bold show loading coefficients for items in each construct.

Table 7
Results of regression analysis (mental decline).

	coefficient	Standard error	Standardized coefficient	t	p-value
constant	0.025	0.288		0.085	.932
FD	**0.075**	0.023	0.123	3.314	**.001**
CS	**0.242**	0.056	0.169	4.360	**.000**
PS	**0.195**	0.039	0.185	5.032	**.000**
JA	**0.108**	0.033	0.121	3.310	**.001**
ED	**0.068**	0.027	0.096	2.491	**.013**

Numbers in bold show loading coefficients for items in each construct.

Table 8
Results of regression analysis (rest defects).

	coefficient	Standard error	Standardized coefficient	t	p-value
constant	1.240	0.208		5.956	.000
FD	**0.036**	0.016	0.073	2.213	**.027**
CS	**0.516**	0.040	0.443	12.873	**.000**
AE	**0.058**	0.034	0.058	1.724	**.085**
JA	**0.060**	0.023	0.083	2.570	**.010**
HE	**-0.124**	0.028	-0.140	−4.381	**.000**

Numbers in bold show loading coefficients for items in each construct.

Appendix. Final instrument

Flight direction (FD)	FD1	My flight operational performance is reduced when I fly a long-haul flight westward to my home.
	FD2	My flight operational performance is reduced when I fly a long-haul flight eastward to my home.
	FD3	My flight operational performance is reduced when I fly a long-haul flight eastward from my home.
	FD4	My flight operational performance is reduced when I fly westward from my home.
	FD5	My flight operational performance is reduced when I have successive eastward or westward long-haul flights after flying in the opposite direction.
	FD6	My flight operational performance is reduced when I have southward long-haul flights from my home.
	FD7	My flight operational performance is reduced when I have northward long-haul flights from my home.
Crew scheduling (CS)	CS1	My flight operational performance is reduced by the current flight and rest time related regulations.
	CS2	My flight operational performance is reduced by the current duty time workload.
	CS3	My flight operational performance is reduced by the current company schedule operation pattern
	CS4	My flight operational performance is reduced by the current irregular patterns of duty and rest patterns.
Partnership (PS)	PS1	My flight operational performance is affected when I fly with a line instructor (check pilot) or auditor pilot.
	PS2	My flight operational performance is affected when I fly with an administration pilot.
	PS3	My flight operational performance is affected when I fly with pilots that are significantly younger or older than me.
	PS4	My flight operational performance is affected when I fly with pilots that had a different background before joining the current airline company.
Aircraft environment (AE)	AE1	My flight operational performance is affected when I try to rest inflight while being exposed to an inappropriate temperature environment.
	AE2	My flight operational performance is affected when I try to rest inflight while being exposed to an inappropriate lighting environment.
	AE3	My flight operational performance is affected when I try to rest inflight while being exposed to inappropriate noise environment.
	AE4	My flight operational performance is affected when I try to rest inflight during turbulence.
Company management (CM)	CM1	My flight operational performance is affected by the current human resources policy.
	CM2	My flight operational performance is affected by the current lack of coordination between departments.
	CM3	My flight operational performance is affected by the current wages policy.
	CM4	My flight operational performance is affected by the current organizational culture of safety.
Job assignment (JA)	JA1	My flight operational performance is affected when I have two sets of quick turnaround flights.
	JA2	My flight operational performance is affected when I have two sets of quick turnaround flights for mid- or long-haul flights.
	JA3	My flight operational performance is affected when I have short-haul multi-leg flights at once.
Hotel environment (HE)	HE1	I sleep deeply at the station hotel.
	HE2	I sleep enough hours at the station hotel.
Ethnic difference (ED)	ED1	I have less concentration than crew members of a different race during long-haul flight.
	ED2	I think I feel more tired than crew members of a different race during early morning flights.
Time zone (TZ)	TZ1	My flight operational performance is affected by my current home base local time.
	TZ2	My flight operational performance is affected when I have a short stay at a station with a large time zone difference.
Dependent factors		
Physical fatigue (PF)	PF1	I make errors in flight operational procedures.
	PF2	I make errors in conversation with crew members or air traffic controllers.
	PF3	I cannot endure my sleepiness during flight operations.
	PF4	I feel difficulty to perform normal flight procedures.
	PF5	I am relaxed and sleepy during flight operations.
Mental fatigue (MF)	MF1	I am unwilling to do anything during flight operations.
	MF2	I still cannot do anything during flight operations.
	MF3	I feel my thinking ability is fatigued.
	MF4	I have trouble thinking clearly during flight operations.
Lack of rest (LR)	LR1	I feel the lack of rest breaks.
	LR2	Overall, my job is difficult physically.
	LR3	I feel I need more rest during flight operations.
	LR4	Overall, my job is difficult mentally.

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