Investigating the Effects of Energy Drink Consumption on Student Pilot Fatigue and Performance Levels

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Dedication

I would like to dedicate this thesis to my mother and father,
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Abstract

A limited number of studies have examined the effects of energy drink consumption on student pilot fatigue and performance in aviation. The results from these studies were inconclusive and inconsistent. The aim of this study is to investigate the effects of consuming Red Bull energy drinks on student pilot fatigue and performance levels. Healthy student pilots participated in this applied Quasi-experiment, who were given either Red Bull energy drinks or bottled water. Fatigue and sleep questionnaires were administered to assess fatigue and alertness levels of the participants. The results indicated there were no significant effects of consuming Red Bull energy drinks on student pilot alertness levels, which was subjectively measured by the Karolinska Sleepiness Scale. At the same time, consuming Red Bull energy drinks had no significant effect on student pilot cognitive performance levels, which was objectively measured by psychomotor vigilance task. However, the performance of participants in the Red Bull energy drink group was improved compared to the performance of participants in the water group, which was measured by faster reaction times, fewer numbers of lapses and errors. Additional, higher number of correct responses and zero number of sleep attacks were also measured. More importantly, the likelihood of error detection by student pilots who consumed Red Bull energy drinks was significant, F (1,108) = 9.12, p = .003.

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Chapter One:The Study Context

1.1 Introduction

The use of energy drinks in the young adult population has been exponentially increasing in recent years (Sawynok, 2011). It is logical to assume that the student pilot population represents a small group of energy drink users. Energy drinks are generally perceived to enhance physical and mental performance (Alford, Cox, & Wescott, 2001). Student pilots who consume energy drinks will likely defend its use when the aviation regulatory body, cognisant of its own safety culture and high standards, questions them about energy drink consumption. However, while the widespread use of energy drinks remains popular, the acceptability of its use in the general population has been controversial. At the same time, there is consistent and conclusive research indicating the physical and mental efficiency of pilots can be reduced by pilot fatigue compared to pilots who have not consumed energy drinks (Caldwell, 2005; Powell, Spencer, & Petrie, 2011). Further research in relation to energy drink consumption on pilot performance is warranted.

Several studies have suggested that there is general concern in the aviation community that pilot fatigue leads to aviation accidents and incidents (Goode, 2003), and the level of concern is increasing (Caldwell et al., 2009). The following list of real world scenarios has been reported by student pilots (L. Yang, personal communication, August 9, 2013):

1. *I am unable to concentrate, cannot repeat clearances back if they contain more than two bits of information, and I cannot even remember my call sign. I have had trouble with fixation on simple tasks*.

2. *I got in the car after the flight training, having covered about half the distance, I got to a roundabout. Instead of continuing west, I came off the roundabout heading east. It was some time before I realised my mistake. I attributed my taking the wrong exit to post-flight fatigue*.

These examples indicate that student pilots have safety concerns about the effects of fatigue in aviation operations. It is not unusual to find fatigue being listed as a probable cause for aviation accidents and incidents. The relationships between pilot fatigue and aviation safety have been well established in numerous of human factors studies (Caldwell, 2005).

1.2 The Research Problem

A large number of studies have tried to evaluate the effects of energy drink consumption among the general population. For instance, consuming Red Bull energy drinks indicated no significant effect on repeated sprint performance in female athletes (Astorino et al., 2012). Similarly, a study by Forbes, Candow, Little, Magnus, and Chilibeck (2007) found that consuming Red Bull energy drinks improved bench press performance among 15 healthy young adults, but it indicated no significant effect in peak power during bench pressing. Their findings were conflicting and unsatisfactory (Forbes et al., 2007). In contrast, some studies have demonstrated the positive effects of energy drink consumption. For example, Cameron (1973) suggested that energy drink consumption enhanced both cognitive and physical performance levels. Similarly, Sawynok (2011) found energy drink consumption increased alertness and decreased fatigue levels.

There are safety concerns about the level of energy drink consumption among young adults. It can create health problems, due to the increase in the amount of caffeine and other active herbal supplements which may multiply potential toxicity (Cameron, 1973). Further studies are needed to fully understand the stimulant effects of energy drinks on the central nervous system.

Unfortunately, few studies have investigated energy drink consumption in student pilots. A large beverage industry has been marketing energy drinks to general population for a variety of uses (Schneider & Benjamin, 2011). It is likely that some pilots have expectations that consumption of energy drinks increases their overall performance and may assist them to manage fatigue, and reduce performance errors. Despite these perceptions, there is little direct evidence that energy drinks influence the alertness and performance of pilots who are fatigued.

Despite inconsistencies in research on energy drink consumption, empirical studies have reinforced the concept that pilot fatigue can be objectively and subjectively measured (Mohler, 1966). These studies have produced some reliable results, such as increased reaction time and increased time of visual accommodation to alternating near and far points of vision (Mohler, 1966). Both commercial and military pilots have suggested fatigue is an important issue in aviation (Caldwell, 2005). Accident statistics, reports from pilots themselves, and operational flight studies all indicated that fatigue continued to affect pilot performance (Caldwell, 2005). At present, it is not clear what the true impact of pilot fatigue and the effects of energy drink consumption are on student pilot flight performance. There is a lack of information on how student pilots experience fatigue and monitor their own levels of tiredness in daily flight training operations, and what common fatigue countermeasures are being used by student pilots.

1.3 The Organisation of the Thesis

Chapter One outlines the aim and background of this study. Literature reviews of fatigue, fatigue countermeasures and energy drink consumption are presented in the following chapters.

Chapter Two reviews the literature on pilot fatigue. This chapter begins with defining fatigue. This leads to an exploration into the complex nature of fatigue. Causes and effects of pilot fatigue are discussed.

Chapter Three presents fatigue countermeasures in an aviation context. In this chapter, aviation fatigue risk management is discussed, followed by pilot fatigue countermeasures with non-pharmacologic and pharmacologic approaches.

Chapter Four reviews the literature on energy drink consumption. Energy drink consumption and its effects on physical and cognitive functioning are discussed. Caffeine and its effects are also reviewed.

Chapter Five presents the methodology, including descriptions of applied Quasi-experimental design, Pittsburgh Sleep Quality Index, Karolinska Sleep Scale and PEBL Perceptual Vigilance Task.

Chapter Six presents the results of the study including data analysis of basic demographics, energy drink consumption, as well as objective and subjective measurements of pilot fatigue and performance. One-way analysis of variance tests, Chi-square tests, mixed model analysis of variance tests, principle component analysis and standard multiple regression were completed.

Chapter Seven presents a discussion of the findings.

Chapter Eight presents the conclusions and some recommendations. The limitations of the study are also discussed and suggestions for further studies are made.

Chapter Two: Pilot Fatigue

2.1 Introduction

A dehydrated, hungry and fatigued pilot is more likely to make mistakes than a well-sustained and rested pilot (Bennett, 2010). A number of studies have investigated factors which are associated with fatigue and its effects on pilot performance (Powell, Spencer, & Petrie, 2010; Ritter, 1993). Unfortunately, the problems associated with pilot fatigue and performance impairments are likely to increase in sustained aviation operations (Meadows, 2005).

According to the International Civil Aviation Organisation (ICAO), pilot fatigue is defined as: "A physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness, circadian phase, or workload (mental and/or physical activity) that can impair a crew member's alertness and ability to safely operate an aircraft or perform safety related duties" (Annex, 2001, p. 1).

Similarly, the Federal Aviation Administration (FAA) has defined pilot fatigue as "A condition characterized 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" (Laws, 2012, p. 22).

These definitions are well-constructed and accepted by the aviation community (Laws, 2012). However, fatigue has been defined in a number of different ways (Avers &

Johnson, 2011). This chapter reviews the empirical, theoretical understanding of fatigue and its complex nature. Some causes and effects of pilot fatigue are discussed separately. Performance modelling is also discussed.

2.2 Empirical Understanding of Fatigue

Several fatigue definitions have been documented within aviation and human factors literature. Empirical understanding of fatigue was developed by the following ergonomists: Bergeret (1953); Evrard (1954) and Cameron (1973).

Bergeret (1953) described fatigue as "impaired ability to maintain physiological or cognitive resources at a desired level due to incomplete recovery from the activity of prior work and previous waking activities" (p. 295). In addition, Evrard (1954) identified that fatigue had psychological, physiological, and emotional implications on performance. Cameron (1973) reported fatigue was a ubiquitous symptom and often affected individuals.

Some studies have focused on defining fatigue, even though it was considered too difficult to define (Aaronson et al., 1999; Chalder et al., 1993; Lee, Hicks, & Nino-Murcia, 1991; Ream & Richardson, 1996). From a physiological perspective, fatigue is: "the end result of excessive energy consumption, depleted hormones, or diminished ability of muscle cells to contract. Anaemia, infection, impaired oxygenation, and other physiological conditions deplete energy reserves by creating an unrelenting physical demand for energy expenditure" (Lee et al., 1991, p. 291). From a psychiatric perspective, fatigue is "a subjective state of weariness related to reduced motivation, prolonged mental activity, or boredom that occurs in situations such as chronic stress, anxiety, or depression" (Lee et al., 1991, p. 291).

Ream and Richardson (1996) investigated various forms of fatigue definitions, characteristics, attributes, dimensions and consequences. Consequently, they described fatigue as "a subjective, unpleasant symptom which incorporates total body feelings ranging from tiredness to exhaustion creating an unrelenting overall condition which interferes with individuals' ability to function to their normal capacity" (p. 527). Despite of all the efforts, there is still a lack of an accurate and unique fatigue definition in the context of aviation. For instance, Bourgeois-Bougrine, Carbon, Gounelle, Mollard, and Coblentz (2003) described pilot fatigue by its symptoms, such as a decrease in alertness, feeling tired, sleepy, and/or feeling exhausted.

Gander et al. (2011) presented an operational definition of fatigue for aviation as: "the inability to function at the desired level due to incomplete recovery from the demands of prior work and other waking activities. Acute fatigue can occur when there is inadequate time to rest and recover from a work period. Cumulative (chronic) fatigue occurs when there is insufficient recovery from acute fatigue over time" (p. 574). However, in the recent publication, Avers and Johnson (2011) argued these pilot fatigue definitions provided "an accurate description but failed to represent the performance consequences associated with fatigue" (p.88). They suggested that pilot fatigue was more than pilot sleepiness in aviation but "a complex state that has psychological, physiological, and emotional implications that can impact the safe performance of routine and non-routine work activities" (p.88). Avers and Johnson's definition (2011) is considered multi-dimensionally constructed and suitable to be used among student pilots within the aviation training environment in this study.

2.3 Nature of Pilot Fatigue

The complex nature of pilot fatigue has been recognised in some earlier research (Chalder et al., 1993; Mohler, 1966). Mohler (1966) documented three aspects of pilot fatigue: physical, mental, psychosomatic and their symptoms (see Table 2.1). Ream and Richardson (1996) outlined the following fatigue characteristics:

1. Fatigue followed exertion;
2. Fatigue was associated with physical or mental weariness and exhaustion;
3. Fatigue comprised comfortless, troublesome or odious feelings;
4. Fatigue caused a decreased functional ability, which was often temporary (p. 521).

Accordingly to Chalder et al. (1993), pilot fatigue is ubiquitous and difficult to describe. Pilot fatigue can be represented as “a single phenomenon”, or “a continuous dimension”, or “a subjective internal feeling” (Chalder et al., 1993, p. 147). Similarly, Ream and Richardson (1996) established that fatigue was a multi-dimensional and complex concept that possessed different attributes. They listed the following critical fatigue attributes:

1. A total body feeling and experience, encompassing physical, cognitive and emotional dimensions;
2. An odious and unpleasant experience which causes distress;
3. A chronic and unrelenting phenomenon;
4. A subjective experience dependent upon an individual’s perception (p. 524).

Table 2.1 Physical, Mental and Psychosomatic Fatigue Symptoms

Fatigue Symptoms (Mohler, 1966, p. 2 - p. 4)
Physical Fatigue Symptoms
Increased Reaction Time
Increased Blood Lactic Acid
Increased Lag in Pupillary Response Time to Light
Increased Time of Visual Accommodation to Alternating Near and Far Points of Vision
Increased Loss of Electrolytes Through Cutaneous Excretory Organs
Increased Urinary Corticosteroids and Catecholamine
Increased Instability of Neuromuscular Coordination
Decreased Strength
Decreased Blood Glucose
Decreased Ability for Rapid Binocular Fusion
Decreased Muscle Tonus
Decreased Circulating Blood Volume
Decreased Muscle Glycogen
Mental Fatigue Symptoms
Increased Anxiety and Irritability
Increased Susceptibility to Error
Increased Tendency to Insomnia
Increased Susceptibility to Depressive States
Increased Tendency to Withdrawal from Vocational Social Undertakings and Hobbies
Increased Tendency to Use Pharmacologic Crutches
Decreased Attention Span
Decreased Libido
Decreased Recent Memory
Decreased Cooperativeness
Decreased Acceptability to Constructive Criticism
Decreased Interest in Personal Care and Hygiene
Decreased Gastrointestinal Efficiency
Psychosomatic Fatigue Symptoms
Headaches
Burning Eyes
Sweating
Heartburn
Chronic Constipation or Chronically Loose Bowels
Chronic Loss of Appetite
Nightmares
Shortness of Breath

According to some research, pilot fatigue is also considered too difficult to measure (Chalder et al., 1993; Lee et al., 1991). Several attempts were made to produce scales without much success. For example, Lee et al. (1991) developed a visual analogue scale to evaluate fatigue severity, which consisted of 13 items in fatigue and five items in energy. It was a valid and reliable instrument to assess fatigue and energy levels in both healthy and fatigued subjects. However, this process is too time-consuming and less accurate. Some subjects might be hesitant about using the extreme ends of 100-mm of visual analogue lines.

Similarly, Chalder et al. (1993) constructed a 14 items scale to measure fatigue, which consisted of eight physical and six mental fatigue items. It is not recommended to be used solely to assess fatigue, but in conjunction with other clinical tools as a fatigue symptom severity assessing instrument. These various studies have been discussed are the foundation for understanding pilot fatigue in aviation. The difficult of describing pilot fatigue and its nature have been documented and acknowledged by the early research and the recent publication.

2.4 Causes of Pilot Fatigue

Pilots are constantly challenged by numerous factors, such as early departures, late arrivals, long duty days, non-standard work hours, night duty, rotating schedules, circadian disruptions, and sleep difficulties, which all can contribute to pilot fatigue (Caldwell, 2005; Eriksen, Akerstedt, & Nilsson, 2006; Flower, 2001; Gander et al., 1994). Extensive research has focused on identifying the factors which can produce and increase fatigue levels (Perhinschi, Smith, & Betoney, 2010). A wide range of factors have been identified that can impact on fatigue in aviation (see Table 2.2). Those factors continue to challenge pilot alertness and performance levels.

Table 2.2 Fatigue Factors

General Factors	Aviation Factors
Rest and Sleep Opportunities	Number of Flight Crew
Age	Composition of Flight Crew
Time Since Awakening	Status of Circadian Acclimatisation
Type of Activity (Physical/Cognitive)	Previous Duty Duration
Time on Task	Total Duty Time
Type of Task(Monotonous/Challenging)	Opportunity for Pre-flight Rest/Sleep
Circadian Rhythm	Opportunity for In-flight Rest/Sleep
Time of Day	Post-flight Recovery and Sleep
Medication/Aids to Alertness	Cockpit Environment/Type of Aircraft
Sleep Restriction	

From the transport industry perspective, industrial and cultural changes are the contributing factors to pilot fatigue, such as increasing financial and management pressure, increasing competition, increasing employee productivity and value, lowering employee numbers and having more flexibility from employee (Dawson, 2000). From the pilot’s perspective, Caldwell (2005) suggested two important pilot fatigue contributing factors: circadian factors and homeostatic factors. In a separate study, Caldwell et al. (2009) added two extra factors: the unpredictable work hours and long duty periods. They argued these were the main contributing factors and have been creating significant issues in aviation.

2.4.1 Circadian Rhythm Disruptions and Sleep Loss

Circadian rhythm disruptions and sleep loss are the main causes of pilot sleepiness and performance impairment in aviation (Caldwell & Caldwell, 2005; Dawson & Fletcher, 2001). Flower (2001) identified that circadian rhythm disruptions often impaired pilot performance, increased fatigue levels, reduced alertness levels and compromised safety. Similarly, Akerstedt, Folkard, and Portin (2004) suggested that pilot sleep loss was directly linked to pilot alertness and performance.

Gundel, Drescher, Maaβ, Samel, and Vejvoda (1995) conducted a study investigating pilot sleepiness in 22 male B767 pilots. Pilots were assessed by EEG recordings and subjective mood ratings during two consecutive night flights of approximately 10 hours each. The results indicated those pilots' sleep patterns during layover (daytime) were shorter and more disturbed compared to their sleep patterns at night time. They experienced increased sleepiness and fatigue during the second of two consecutive night flights, because of reduced quality and quantity of sleep between flights.

Caldwell and Caldwell (2005) investigated the following reasons that contributed to pilot sleep loss in the operational aviation in their study:

1. The sleep environment was less than optimal;
2. The state of the individual was incompatible with the ability to sleep;
3. The sleep opportunity occurred at a time that was not biologically conducive to rapid sleep onset and/or sufficient sleep maintenance due to circadian physiological rhythms associated with time of day variations and even from shift lag or jet lag (p. 40).

Another study was carried out by the Institute of Aerospace Medicine to investigate pilot fatigue caused by sleep loss and circadian rhythm disruptions in the Indian Air Force (Taneja, 2007). A total of 83 pilots participated in the study. They found that

33.7% of pilots reported that they had felt sleepy or drowsy in the cockpit due to sleep loss at some time, 36.1% of pilots considered that sleep loss was a common phenomenon among aircrew. In addition, 40% of pilots might often be falling into micro-sleep[1] in the cockpit due to sleep loss and fatigue, and 18% of pilots considered falling into micro-sleep in the cockpit to be the norm in fighter flying.

Samn and Perelli (1982) documented that pilot performance decrement in U.S. Air Force airlift missions was due to loss of sleep and circadian rhythm disruptions resulting from transiting multiple time zones. These aforementioned studies have examined the effects of sleep loss and circadian rhythm disruptions on pilot fatigue and performance in the aviation literature.

2.4.2 Long and Short-Haul Flight

Both long and short-haul flights can be the causes of pilot fatigue in aviation (Bourgeois-Bougrine et al., 2003). Long-haul commercial and military pilots are involved in flights across multiple time zones. It can easily cause circadian deregulation and affects pilot physiological and psychological performance functions (Gander & Signal, 2008; Gundel et al., 1995; Powell, Spencer, & Petrie, 2011).

Powell, Spencer, and Petrie (2011) conducted a pilot fatigue study in Air New Zealand long-haul B777-200 operations. They used the Samn-Perelli seven point scale (Samn & Perelli, 1982) prior to descent on each flight to assess pilot fatigue levels and 4629 responses were collected. The results indicated that the highest sets of scores were

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[1] Micro-sleep: involuntary sleep lapses lasting for a few seconds to a few minutes (Strauss, 2006).

obtained at the end of long-haul night time sectors. Overall, pilot fatigue levels on the long-haul sectors were significantly higher than other sectors.

In addition to long-haul pilot fatigue studies, some short-haul studies have also made a considerable effort into investigating pilot fatigue. For example, Powell et al. (2007) conducted pilot fatigue tests in Air New Zealand short-haul B737 operations. Samn-Perelli seven point scale prior to descent on each flight was administered and 1379 responses were collected. The results indicated that some short-haul operations were more fatiguing than others. At the same time, they found that the contributing factors to fatigue in short-haul operations were: 33.3% responses for numbers of sectors, 33.0% responses for duty length, and 12.6% for time of day.

Likewise, another study was conducted to investigate fatigue-related issues among 162 pilots in the short-haul operations (Jackson & Earl, 2006). The results indicated that 75% of the pilots reported that they were severe fatigued and 81% of the pilot reported that their fatigue levels were worse than two years ago. They found that severe fatigue occurrences were reported more frequently and having higher fatigue ratings by low-cost airline pilots than scheduled airline pilots. Interestingly, regular use of discretion time[2] appears to be associated with fatigue by short-haul pilots. These studies have examined the effects of long and short-haul operations on pilot fatigue and performance in aviation.

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[2] Discretion time: it is an extended period of time needed to complete a duty due to unforeseen circumstances (Jackson & Earl, 2006).

2.4.3 Scheduling, Time of Day and Length of Duty

Pilot schedules can lead to fatigue, and untimely schedules can increase the chances for aviation accidents and incidents to occur (Bourgeois-Bougrine et al., 2003; Drury, Ferguson, & Thomas, 2012; Goode, 2003; Powell, Spencer, Holland, & Petrie, 2008). Goode (2003) found the proportion of accidents associated with pilots having longer duty periods was higher than pilots having shorter duty periods. Their results indicated there was a significant correlation between the proportion of accidents and pilots having longer duty hours. Their findings suggested that there were a 1.7 times higher accident proportion relative to pilots on ten to twelve hours of duty time and a 5.6 times higher accident proportion relative to pilots with 13 or more hours of duty time.

Bourgeois-Bougrine et al. (2003) suggested that pilot fatigue was mainly due to work schedules, time of day, length of duty for both commercial and military pilots. Similarly, Powell et al. (2008) identified that pilot schedule, time of day, length of duty were fatigue contributing factors in their study. 3023 questionnaires were received from Air New Zealand B737-300, B767, and B747-400 operations. The results indicated that the strongest influence on fatigue was time of day. The highest fatigue levels being recorded were between 3am and 6am. 4pm and 7pm were the lowest of the fatigue levels being recorded. The findings suggested that fatigue increased with the length of duty and the effect of length of duty was dependent on the time of day.

A web-based survey was conducted among U. S. Air Medical pilots in relation to fatigue and sleep-related issues (Gregory, Winn, Johnson, & Rosekind, 2010). A total of 697 responses were received. The results indicated that 98% of the pilots stated that they worked in a fixed schedule, 2% were on calls. More specifically, 48% stated that they were on a 3/3/7[3] schedule and 41% were on a 7/7[4] schedule. The findings suggested that 84% of pilots reported that their fatigue had affected their performance. The findings also suggested that scheduling like 3/3/7 and 7/7 were the most common contributable fatigue-related practices. Likewise, Steptoe and Bostock (2012) suggested that the typical work pattern of 5/3/5/4[5] among low-cost airline pilots could easily exceed the CAP 371[6] limit of three consecutive early duties. These studies have examined the effects of scheduling, time of day and length of duty on pilot fatigue and performance in aviation.

2.4.4 Crew Size and Number of Sectors

Crew size can be a contributing factor to fatigue in some studies (Eriksen, Akerstedt, & Nilsson, 2006; Powell et al., 2011). For example, Powell et al. (2011) identified that post-flight fatigue levels of three-pilot crew from Auckland to Hong Kong were significantly higher than the post-flight fatigue levels of four-pilot crew from Auckland to Vancouver. Eriksen and Akerstedt (2006) examined pilot fatigue amongst two and three-pilot crews operations. Their findings suggested that the reduction of crew size by one pilot was associated with moderately increase levels of sleepiness. Powell et al. (2008) suggested the number of sectors was one of the fatigue contributing factors in their study. Their findings suggested that two-sector operations were a 0.56 times higher in pilot fatigue levels than single-sector operations.

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[3] 3/3/7: 3 12-hours day shifts, follow by a day off, then 3 12-hours night shifts and follow by 6 or 7 days off (Gregory et al., 2010).

[4] 7/7: 7 day shifts and 7 days off, then 7 night shifts and 7 days off (Gregory et al., 2010).

[5] 5/3/5/4: 5 early duties, 3 days off, 5 late duties, 4 days off (Steptoe & Bostock, 2012).

[6] CAP 371: Avoidance of Fatigue in Air Crews—the regulations set a work pattern for flight crews and cabin staff designed to prevent the onset of fatigue (Steptoe & Bostock, 2012).

2.4.5 Miscellaneous Factors

Apart from these major factors, there are more pilot fatigue contributing factors in aviation. For example, Mohler (1966) documented the environmental factors such as “temperature, humidity, colour, light intensity, noise, vibration, odour, gases, barometric conditions and ozone” (p. 2), which all can contribute to pilot fatigue. Similarly, Strauss (2006) discussed that aircraft environmental factors which could make pilots susceptible to fatigue in their study. These included “movement restriction, variable airflow, low barometric pressure and humidity, noise, and vibration” (p. 1).

Houston, Dawson, and Butler (2012) identified other fatigue contributing factors, such as the quality of the hotel accommodation, distance between airport and the hotel/home, commuting time, childcare, disturbed rest, commute to workplace and noisy neighbours. In addition, the results of their research indicated that 27% of pilot fatigue was caused by rostered duty pattern, 24% were operational disruption, and 17% were layover accommodation, and 23% were by a domestic issue.

Airport of origin can be a contributing factor to pilot fatigue (Powell et al, 2007). They identified that pilots departing from Dunedin and Wellington scored higher levels of fatigue than pilots departing from Auckland and Christchurch, which was due to being away from home base and the need to stay overnight.

Nesthus (2001) discussed that the lack of food and dehydration were contributors to pilot fatigue. Gander et al. (1994) suggested that the quality of the landing site and air traffic control could also affect pilot fatigue. Bennett (2010) found some pilots did not rest on their rest days and they worked other jobs around house or cars, or businesses, which all increased the risk of being fatigued when returning to duties. Some fatigue factors can be easily resolved, while others maybe require more effort. Unfortunately, all fatigue factors represent a risk to the operation and have the potential to generate more risks and hazardous situations. These aforementioned studies have investigated variety of causes of pilot fatigue in the aviation literature.

2.5 Effects of Pilot Fatigue

The effects of pilot fatigue on the individual level have been extensively studied in the field and laboratory sittings (Bergeret, 1953; Caldwell, 2005; Eriksen et al., 2006; Flower, 2001; Gander et al., 1994; Pearson, 1957). Petrie and Dawson (1997) conducted a pilot fatigue study among 188 Air New Zealand pilots ranging from 767 and 747-200/400 operations. They identified ten most frequent fatigue symptoms:

1. Feel Sleepy;
2. Feel Low in Energy;
3. Feel Mentally Slow;
4. Lack of Concentration;
5. Become Grouchy or Irritable;
6. Sore Eyes;
7. Become Forgetful;
8. Have Difficulty Planning;
9. Become Easily Dismaled;
10. Miss Things (p. 252-p.258).

Dinges (2008) described that fatigue occurred in the brains of all pilots and manifested in behaviours which could increase risks of adverse events. An important issue in aviation is the evaluation of the effect of fatigue on pilots (Powell et al., 2011). Fatigued pilots become more prone to distraction and suffer from a narrowing of perceptual focus. They reserve their attention for issues of aircraft controls, such as heading, airspeed, and altitude (Ritter, 1993). All of these can impair pilot performance, reduce alertness and ultimately compromise safety (Dawson, 2000; Gunzelmann, Gross, Gluck, & Dinges, 2009; Ritter, 1993). Likewise, Dawson (2000) identified that fatigue-related impairments had a similar influence as moderate alcohol intoxication. The effect of fatigue delays response and reaction times, negatively influences logical reasoning and decision making, and impairs hand-eye co-ordination.

2.5.1 Physical Health Issues

Fatigue can lead to some health issues (Caldwell et al., 2009; French & Morris, 2003; Gander et al., 1994; Steptoe & Bostock, 2012). Gander et al.(1994) studied 32 helicopter pilots in services to North Sea oil rigs in Aberdeen of Scotland. The results indicated that pilots were more fatigued on post trip days than on pre-trip days. Cumulative effects of duty-related activities and sleep loss were contributing to higher fatigue levels among the pilots. An increasing number of physical health issues were reported, such as the incidence of headaches increased twofold, back pain increased twelvefold and burning eyes increased fourfold.

Jackson & Earl (2006) found pilots who were regularly flying into their discretion hours had lower physical and psychological health levels, higher overall fatigue scores, and poorer self-rated general health. French and Morris (2003) suggested cumulative sleep debt/sleep loss among pilots could cause immune system disruptions, more colds and other illnesses. Likewise, Caldwell et al. (2009) found higher incidences of stomach problems (especially heart-burn and indigestion), menstrual irregularities, colds, flu, weight gain, and cardiovascular problems in many aircrews. Compared to pilots who are well rested, fatigued pilots are likely to have some health issues.

2.5.2 Psychological Issues

Pilot fatigue can also lead to psychological issues. There is an extensive literature documenting these relationships. For example, pilot anxiety and depression are strongly correlated with pilot fatigue (Gander et al., 1994; Steptoe & Bostock, 2012). Gander et al. (1994) found that the earlier pilots went on duty, the lower their social interactions became by the end of the day. Similarly, the longer they spent on duty, the more moody they became.

Miller, Fisher, and Cardenas (2005) described that mood swings and irritability were well-known hallmarks of pilot fatigue. The frequent reports by shift workers among air force personnel of depression and excessive drinking were also disturbing. Steptoe and Bostock (2012) established that anxiety and depression did not vary by gender, age or years of employment. In addition, the fatigue symptoms were slightly higher in Captains than First Officers.

Steptoe and Bostock (2012) conducted a survey of fatigue and well-being among 492 commercial airline pilots from UK, Germany, France, and Italy. The results suggested that the levels of self-reported fatigue, sleep problems, symptoms of anxiety and depression were higher than the general population. They found that 45% of the pilots were suffering from significant fatigue. One in five pilots reported that their abilities were compromised in flight by fatigue more than once a week. Pilot fatigue has been identified as a contributing factor in psychological issues. These studies have examined the physical health and psychological issues associated with pilot fatigue in aviation.

2.6 Fatigue and Performance Modelling

The aviation community is interested in understanding fatigue and performance models to assist its risk assessments and predictions. Biomathematical performance models have been developed to predict cognitive performance in sleep deprivation to identify errors and risks (Akerstedt & Folkard, 1996; Dawson & Fletcher, 2001; Jewett & Kronauer, 1999). These models contain equations to calculate the fatigue risk metrics based on factors, such as sleep history, time of day and workload. Existing biomathematical models are derived from the two-process theory of alertness, which claimed that the human arousal system consisting of two primary components: a circadian system and a sleep homeostasis system (Akerstedt et al., 2004; Caldwell, Chandler, & Hartzler, 2012).

2.6.1 Parametric Modelling Approaches

The following seven models were developed based on existing data and empirical studies by using known principles and mathematical equations to predict measures of pilot fatigue and performance (Akerstedt & Folkard, 1996; Belyavin & Spencer, 2004; Dawson & Fletcher, 2001; French & Morris, 2003; Jewett & Kronauer, 1999; Roach, Fletcher, & Dawson, 2004). Therefore, these were considered as parametric modelling approaches or “white-box” models approaches (Reifman, 2004).

Akerstedt and Folkard (1996) constructed a mathematical/computer model based on subjective alertness data to predict alertness with three parameters: circadian, homeostatic and sleep inertia. It was named as the Three-Process Model of Alertness (TPMA). This model was able to predict sleep latency[7], sleep termination and give a reasonable accurate prediction of reduced alertness and performance in some applied situations. However, it was limited by other factors, such as pilot stress, sleep conditions and drugs. Therefore, this model was only used when assessing of general effects of pilot schedules in aviation.

Jewett and Kronauer (1999) constructed a similar mathematical model with the same parameters. They considered the effects of light in the circadian component. This model has predicted the fine details of neurobehavioral data in some pilot sleep deprivation studies. By comparison, both models had the same parameters. However, the earlier model was constructed based on limited experimental data. Different equations and algorithms were used during the development of the models and different relationships amongst each component were analysed. Some unforeseeable circumstances like pilot sleep disturbance and use of sleeping drugs have limited the use of both models in aviation.

Dawson and Fletcher (2001) constructed a quantitative input-output model for pilot fatigue, which was based on three contributors: the duration and timing work period, recency of shifts. At the same time, Weitzel and Geraci (2001) constructed a triangular points pilot fatigue model consisting of manifestations (cognitive, physiological, and psychological), degradations (alertness, situation awareness and crew resource management), and innovations (philosophy, policies and practices). In comparison,

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[7] Sleep latency: the amount of time it takes to fall asleep after the lights have been turned off (Buysse et al., 1989).

Weitzel and Geraci’s (2001) model provided a better framework for pilot fatigue predictability and performance than Dawson and Fletcher’s model (2001).

French and Morris (2003) introduced a fatigue algorithm–the FAtigue DEgradation (FADE) tool. It was initially developed to predict fatigue levels of 18 pilots in the 52-hour sleep deprivation experiment. It was consisted of time awake, circadian time, parabolic recovery. They found that there was a linear relationship between time wake component and circadian time during the development of this model.

Roach, Fletcher, and Dawson (2004) developed the Fatigue Audit InterDyen (FAID) Model for estimating pilot fatigue. It was based on the balance between two components: fatigue produced during work periods and fatigue recovery during non-work periods. The value of each component was dependent on length and circadian timing of work and non-work periods, recency of work and non-work periods. This model provided a reasonable estimate of work-related fatigue linked with duty schedules. It was simple and affordable to be implemented by government and aviation sector.

Belyavin and Spencer (2004) constructed the QinetiQ Alertness Model, which consisted of circadian rhythm and the sleep/wake process. The output had scale of lowest level of alertness 0 to highest level of alertness 100. It provided support for the use of the alertness model for the prediction of performance. It has been adapted as the basis of the computer program system for aircrew fatigue evaluation and used at the heart of the System for Aircrew Fatigue Evaluation (SAFE).

Furthermore, a good understanding of parametric modelling for individual pilots can advance the model predictions and improve its accuracy.(Caldwell, Chandler, & Hartzler, 2012). The existing models were constructed based on parametric approaches, which provided a significant level of knowledge in understanding pilot fatigue and performance prediction in aviation.

2.6.2 Non-parametric Modelling Approaches

The construction of fatigue and performance models with alternative approaches, such as non-parametric modelling have been investigated in human factors research (Reifman, 2004). Non-parametric modelling can give near real-time estimation and prediction of individual pilot performance. However, one of the key limitations is the requirement of large data from each subject (Gunzelmann, Gross, Gluck, & Dinges, 2009).

Perhinschi et al. (2010) developed a fuzzy logic-based online detection scheme for pilot fatigue. It characterised pilot condition in all situations adequately. In their flight simulator experiments, they established that pilot performance impairment due to fatigue could be detected by monitoring pilot control inputs and aircraft/flight status. This model was a viable alternative to detect pilot fatigue based on physiological data, such as electrical activity of the brain, pulse and body temperature. It could measure and make connections to pilot comfort levels and their abilities to perform the task.

Non-parametric models can be more effective for fatigue countermeasure and prevention compared to the parametric models. Gaydos, Curry, and Bushby (2013) constructed a subjective peer-to-peer fatigue rating system to address the limitations of existing parametric models. This system required pilots to provide anonymous weekly fatigue rating scores of other pilots. The scoring pilots were required to have considerable familiarity with the scored pilots to be able to sense how much they deviated from their baseline. The findings suggested that the peer-to-peer system gave an external perspective on pilot fatigue since self-awareness of fatigue was fallacious and non-multi-dimensional. However, group/peer fatigue could impact on scoring and make the rating system unreliable. Parametric and non-parametric pilot fatigue models have been used to predict and estimate the impaired performance of pilots in aviation. Some of the models not only can improve pilot scheduling, but also optimise the timing for pilots to apply fatigue countermeasures.

2.7 Summary

In summary, pilot performance can be systematically affected by a range of factors. This chapter included some empirical and theoretical understandings of pilot fatigue and its nature. Fatigue causes, its effects and different performance models were discussed. In conclusion, pilot fatigue is not a one-dimensional phenomenon, but rather the product of several (Caldwell et al., 2009). It is primarily associated with sleep loss and pilot schedules in long and short-haul flights (Bourgeois-Bougrine et al., 2003). It has long and short-term safety and health consequences in aviation (Bergeret, 1953).

Chapter Three:Fatigue Countermeasures in Aviation

3.1 Introduction

Managing fatigue is an important component in aviation. From a safety perspective, improperly managed fatigue can impose a significant risk to crew, passengers and aircraft (Bergeret, 1953; Caldwell et al., 2009; Powell et al., 2008; Taneja, 2007). In an early human factors study, Bergeret (1953) found one of the main links between fatigue and safety relied on crew performance management in particular on crew decision-making process when impaired by fatigue.

Pilots face an increasing challenge of fatigue and they have adopted varies of fatigue countermeasure strategies in their operations. For example, Roach, Petrilli, Dawson, and Thomas (2006) identified the following fatigue countermeasure strategies on the flight deck: napping, consuming caffeine and cross-checking. Bergeret (1953) suggested two main types of fatigue strategies: strategies for alertness management and strategies for performance protection. Similarly, Rosekind, Gander, and Dinges (1991) classified fatigue countermeasures into two categories: preventive and operational.

Physiological effects of fatigue can be quite similar among pilots, but countermeasures can be different (Taneja, 2007). For example, the results of Gregory et al's (2010) study indicated that 42% of the pilots used napping, 12% of the pilot were exercising and doing more activities, 8% of the pilot reported that they would eat food, and 6% would consume caffeine-related products. In contrast, the results of Bourgeois-Bougrine et al's (2003) study indicated that 7% of pilots declared that they did not have strategies to cope with fatigue and 3% of the pilots failed to respond to this question. The remaining 90% of the total 1909 strategies were classified into three main types: rest and sleep management, activity management, and lifestyle. In this chapter, fatigue risk management and some common fatigue countermeasures are discussed.

3.2 Fatigue Risk Management

According to Gander et al. (2011), fatigue risk management is “the planning and control of the working environment, in order to minimise, as far as is reasonably practicable, the adverse effects of fatigue on workforce alertness and performance, in a manner appropriate to the level of risk exposure and the nature of the operation” (p. 574). Fatigue can be managed at three levels in aviation: prevention, detection and recovery (Bergeret, 1953). Similarly, fatigue management strategies should be designed to prevent, detect and reduce fatigue (Dinges, 2008). Caldwell and Caldwell (2005) discussed the following strategies to prevent sleep deprivation in the operational aviation:

1. Ensure adequate manpower levels to properly staff all work periods;
2. Consider scheduling of naps or taking advantage of opportunities for naps;
3. Establish work/rest schedules that enable personnel to gain sufficient restorative sleep in their off-duty hours (p. 47).

The importance of developing fatigue management strategies in aviation is due to circadian and sleep related pilot fatigue, which can occur in some operations (e.g., night flights, trans-meridian[8] and long-haul flights). In extreme cases, fatigue-induced impairment associated with trans-meridian and long-haul flight may be so severe as to

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[8] Trans-meridian: flight across one or more time zones (Roach, Rogers, & Dawson, 2002).

contribute to an incident or accident (Roach, Rogers, & Dawson, 2002). It is recommended to take individual fatigue cause into account when constructing a fatigue countermeasure strategy. It needs to be based on practicality and the likelihood of producing positive outcomes. It needs to be balanced from regulatory perspective. Most importantly, it should not violate the privacy rights of individual pilots (Caldwell et al., 2002; Caldwell et al., 2009; Dinges, 2008).

For example, Caldwell et al. (2009) examined crew rest, flight and duty time guidelines based on the FAA pilot fatigue regulations in their fatigue risk management study. Similarly, Mason (2009) investigated an alternative regulatory approach of a fatigue risk management system and a non-traditional approach for ultra-long-range flights. In addition, Gander et al. (2011) suggested the following three levels of safety management in their pilot fatigue management study:

1. Suppression of risk by eliminating schedules that associated with high levels of fatigue;
2. Mitigations of the risk of fatigue by providing additional crew members and sufficient time for in-flight and layovers sleep;
3. Strategies to maintain operational safety when crewmembers are fatigued (p. 583).

These aforementioned studies have suggested that fatigue-related regulatory management needs to be based on fatigue education, scientific research and regulatory measures by the aviation community.

3.2.1 Fatigue Education

Eduction has indicated a signifcant effort in managing pilot fatigue (Caldwell et al., 2009). Both military and civilian aviation have focused on fatigue education. The implementation of fatigue education has played a significant role in managing fatigue (Caldwell, 2005). Fatigue factors include regulations, flight schedules, physiological needs, or personal sleep habits (Caldwell et al., 2012). Educational efforts are essential for ensuring a thorough understanding of pilot fatigue amongst the aviation community (Caldwell, 2005).

The National Aeronautics and Space Adminstration (NASA) Ames Fatigue Countermeasures program was formed in 1980 in the U.S to investigate the effects of fatigue and fatigue solutions for pilots (NASA, 2000). In the U. S. military, education on fatigue has been an intergral part of pilot training. Its aviation units from Army, Navy and Air Force have conducted a range of studies on fatigue occurrence, fatigue-related problems and fatigue countermeasures (Caldwell, Gilreath, Erickson, & Smythe, 2000).

Pilots need to be equipped with basic information concerning fatigue, its causes and consequences for safety, and how they can improve fatigue management in aviation. Caldwell (2005) described one of the keys to address fatigue in operational aviation was education. Similarly, Bourgeois-Bougrine et al. (2003) suggested pilots should be made aware of fatigue causes and its effects from either self-reported or peer-reported approaches. The dangers of fatigue must be recognised for safety and effective performance in aviation operations. For example, Reis, Mestre, and Canhão (2013) identified that pilot fatigue became a risk and safety issue among Portuguese commercial airline pilots. They found that the majority of pilots had good awareness of individual fatigue levels. However, they did not prefer to report and document their fatigue occurrences to the airline companies, even though the reporting process was confidential.

Pilot fatigue is complex and the solutions are difficult to construct. These can be managed through fatigue education (Weitzel & Geraci, 2001). Fatigue education is one of the strategies to enhance awareness of fatigue causes and effects, and its countermeasures. It is about learning the dangers of pilot fatigue, the causes of sleepiness on the flight deck, and the importance of sleep and proper sleep hygiene when pilots are off duty. Being aware of having adequate sleep, minimal sleep loss and the ability to exert control over sleep–wake schedules are important among pilots in aviation (Taneja, 2007).

3.2.2 Regulatory Measures

Aviation regulatory body has constructed the fatigue countermeasure regulations based on the scientific research. According to ICAO and FAA, a series of regulatory measures and actions in regards to commercial air transport pilot fatigue and its countermeasures has been implemented. These regulations are primarily associated with pilots ageing, including a mandatory retirement age, regular medical assessments for fitness to fly, and limits on the duration of duty (FAA, 2007; ICAO, 2006a).

Most countries have adopted regulations to restrict the number of hours worked by pilots in order to prevent the onset of fatigue. For example, in the U.K, there are absolute limits of 100 hours of flight duty in any 28 days, and 900 hours of flight duty in any twelve months under CAP371 (Steptoe & Bostock, 2012). Similarly, in the U.S, a pilot cannot exceed 290 hours, of which no more than 100 can be flight time in any 28 days. During 365 consecutive days, pilots cannot exceed 1,000 flight time hours (FAA, 2007).

3.3 Fatigue Countermeasures

Fatigue is a known risk factor in the operational environment, and it warrants treatment with scientifically validated fatigue countermeasures (Caldwell & Caldwell, 2005). The implementation of napping, bunk sleeping, exercising and maintaining good nutrition are the common fatigue countermeasures among pilots during in-flight phase. These countermeasures are considered as non-pharmacologic fatigue countermeasures. Other countermeasures such as using hypnotics and melatonin have also been adopted as pharmacologic fatigue countermeasures among pilots in pre-flight and post-flight phase.

3.3.1 Nap

Scientific literature reinforces the fact that rest and sleep are important factors in human performance (Goode, 2003; Taneja, 2007). With an early study, Mohler (1966) suggests that resting becomes mandatory for a given person when fatigue builds up. Similarly, Bourgeois-Bougrine et al. (2003) identified rest and nap were the primary strategies used for coping fatigue among pilots. There is a general agreement that napping during short breaks is the most common way to address sleep loss in aviation. It is a useful fatigue countermeasure in continuous work situation. However, there are fewer consensuses on how cockpit napping should be managed as an effective operational strategy. Because of individual sleep and circadian rhyme varies significantly from person to person (Driskell & Mullen, 2005; Flower, 2001; Karlen, Cardin, Thalmann, &

Floreano, 2010). Bourgeois-Bougrine et al (2003) found that 41% of pilots reported that they took cockpit naps lasting for 20 to 30 minutes compared to 14% pilots reported they closed their eyes for five minutes. Additionally, Bourgeois-Bougrine et al. (2003) found napping prior to a duty increased with age, respectively pilots less than 35 (17%), pilots between 35 and 44 (28%), and pilots more than 44 (36%) would likely to nap.

Driskell and Mullen (2005) conducted a meta-analysis of fatigue literature to investigate usefulness of napping as fatigue countermeasure. They examined twelve studies and the results indicated that napping reduced the effects of sleep loss and it reversed the effects of sleep deprivation under certain conditions. Their findings suggested that the overall measurement of napping effect was “essentially equivalent for measures of performance and for measures of fatigue” (p. 374), longer naps increased performance and the beneficial effects of naps deteriorated after longer post nap intervals. Similarly, Gregory et al. (2010) found that 42% of the pilots responded that napping as the answer for combating fatigue in a fatigue countermeasure survey.

In situations where sleep is possible but the amount of sleep is limited, napping prior to pilot duty is the most effective non-pharmacological technique for restoring alertness and fatigue in aviation (Caldwell et al., 2009; Petrie & Dawson, 1997; Petrie, Powell, & Broadbent, 2004). Interestingly, in Gregory et al’s (2010) study, 94% of the pilots reported that they had a separate room designated for resting, 96% of the pilots indicated that a bed was available in the rest area. 93% reported that their companies did not have any restrictions or limitations for sleeping on duty when there was no flying. In addition, they found that 51% of the pilots reported that they could get six hours of sleep during a night shift, and 30% of the pilots reported they would sleep as much as possible during the day before a night shift, and another 45% indicated that they generally took more than one hour nap prior to duty.

3.3.2 Bunk Sleep

Another technique for minimising the impact of sleep loss and continuous duty among pilots is bunk sleeping. Sometimes, there can be one or more pilots resting in a designated area in the passenger compartment or in a crew bunk while other pilots maintain control of the aircraft. Most airlines permit pilots to use scheduled breaks for sleeping on the long-haul flights (Caldwell, 2005).

Implementing bunk sleeping is extremely helpful for sustaining pilot alertness and performance. In a four-pilot crew arrangement, pilots commonly get more than five hours of sleep when resting in a bunk during 13–16 hours long-haul flights (Caldwell, 2005; Eriksen et al., 2006). Some B-2 bomber missions last for over 30 hours. One of the pilots can sleep in a bunk located behind the seats during low workload flight phases while the other pilot maintains control of the aircraft. On-board sleep is considered be an important fatigue countermeasure for many type of long-range flight operations (Caldwell, 2005).

Fatigue issues can be resolved with quality rest and sleep (Drury et al., 2012). Fatigue countermeasures, such as napping, sleeping and resting aboard the aircraft or at base through different types of crewing and rest practices are commonly adopted (Bourgeois-Bougrine et al., 2003). These strategies directly associated with pilot alertness and performance. However, sleep inertia associated with napping and bunk sleeping can affect pilot mood and cognitive performance. Therefore, Caldwell, et al. (2002) suggested the following methods to minimise sleep inertia in aviation operations:

1. Avoid high levels of sleep deprivation.
2. Place naps in the morning hours.
3. Keep the nap period short[9] or persist[10].
4. Avoid awakening personnel around the circadian trough[11] (p. 4).

The implementation of napping and bunk sleeping can affect and be affected by the subsequent sleep. Pilots need to be aware of factors when adopting these strategies, such as timing, length and the placement of naps or bunk sleep with regards to the phase of the body clock (Akerstedt et al., 2004; Caldwell et al., 2009).

3.3.3 Activities, Breaks and Social Interaction

Physical exercise or mild activities (e.g., stretching, isometrics, writing, chewing gum, changing in posture) or taking a break, or increasing social interactions can improve the levels of alertness and fatigue among pilots in the highly automated cockpit environment. Inversely, lack of involvement (e.g., just listening) can be a sign of having a declined alertness (Caldwell et al., 2009; Drake, 2008). Neri et al. (2002) investigated the effectiveness of the controlled breaks as a fatigue countermeasure.14 two-pilot crew were assessed by physiological tasks and subjective sleepiness rating in a B747-400 flight simulator. The results indicated that pilots received five short breaks during cruise phase had a significantly greater alertness levels for at least 15 minutes in post-break than pilots received one break in the middle of cruise.

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[9] Short: less than 45 minutes (Caldwell et al., 2002).
[10] Persist: at least 110-120 minutes (Caldwell et al., 2002).
[11] Circadian trough: approximately between 0300 and 0400 (Caldwell et al., 2002).

Most pilots are aware of the need to keep high morale by having conversation, joking and having humour played in the flight decks when fatigue starts to intrude during long-haul flights (Bennett, 2010). Petrie and Dawson (1997) identified that mostly used active coping fatigue strategies among pilots on the flight deck were to “keep busy with other activities, keep mind busy and keep up a conversation” (p. 256). These were considered more useful than consuming coffee. Active involvement in conversation and regular breaks prior to and during flight can improve alertness and performance (Drake, 2008; Neri et al., 2002).

3.3.4 Caffeinated Drinks

Caffeinated drinks (e.g., coffee, tea, or soft drinks) are the only alertness-enhancing substances allowed in civilian aviation (Caldwell, 2005). Consumption of caffeinated drinks is one of the most popular measures to boost alertness among pilots (Roach et al., 2002). Petrie and Dawson (1997) identified that drinking coffee was one of the five factors used by pilots to cope with fatigue on the flight deck. In a separate study, Gander et al. (1994) found pilots consumed 42% more coffee on trip days than pre and post trip days. They consumed more caffeine in the early morning and in the mid-afternoon. Similarly, Taneja (2007) found that 81.9% of pilots reported that drinking tea and coffee were the preferred fatigue countermeasures.

However, strategic consumption of caffeine when feeling actually fatigued rather than at regular intervals throughout the day is recommended (Taneja, 2007). Research suggested that caffeine use in a strategic manner (e.g., best timing and effective dosage) could provide the greatest benefit for individuals, with up to a 30% boost in performance. It has potential negative effects on the subsequent nap and/or sleep (Gregory et al., 2010; Taneja, 2007). Therefore, pilots should be aware of this issue.

3.3.5 Pharmacological Fatigue Countermeasures

Non-pharmacological fatigue countermeasures cannot always be a satisfactory practice among pilots in aviation. The requirement of using additional ameliorative strategies to meet the demands of continuous and sustained operations is increasing (Meadows, 2005). Petrie, Powell, and Broadbent (2004) documented that pilots varied in their abilities to cope with fatigue and adopt strategies to manage fatigue. They found that 8.7% of the pilots used the prescribed hypnotics, 7.2% used melatonin and 10.4% used other alternative medicines to manage fatigue among 251 Air New Zealand pilots. Likewise, Caldwell (2003) recommended that the use of caffeine as the “first line” (p. 129) of pharmacological approach to sustaining alertness and performance in sleepy pilots.

In military aviation, the use of stimulants to combat fatigue has a long history. For example, during World War II, it was reported that British bomber pilots were using amphetamines to sustain their alertness levels during long-haul flights. Similarly, German and Japanese pilots were using other stimulants to combat sleep deprivation. In recent U.S military operations (e.g., Desert Storm, Iraqi Freedom, and Enduring Freedom), the use of dextroamphetamine among F-16 fighter and B-2 bomber pilots in long-haul flights was also reported. (Meadows, 2005).

Caldwell and Caldwell (2005) discussed the use of hypnotics and stimulants by pilots in the U.S. military. They exhaustive reviewed each of the currently approved compounds in their study. For example, sleep-promoting compounds (e.g., temazepam, zolpidem, and zaleplon) and alertness-enhancing compounds (e.g., caffeine, modafinil and dextroamphetamine) were analysed. The use of these compounds has been approved in the U.S Air Force.

Paul, Gray, Sardana, and Pigeau (2003) investigated the effectiveness of using melatonin and zopiclone as sleep facilitators among pilots. 30 Canadian C-130 aircrew participated and trialled each of the three drug conditions (placebo, melatonin and zopiclone) in three missions during 27 months long operation to Bosnia. Repeated measures data were collected from wrist actigraphy devices and questionnaires. The findings suggested that the use of melatonin and zopiclone provided some sleep benefits, such as longer sleep, shorter sleep latency, less sleep episodes, more time spent awake after sleep onset, much easier returning to sleep after awakening and higher quality of sleep compared with the placebo.

However, Drake (2008) argued that the implementation of pharmacological fatigue countermeasures could not be the answer to combat sleepiness for fatigued pilots. He suggested that performance-inhibiting side effects of these countermeasures could induce sleep negatively. There is no substitute for real sleep for pilots. Certain sleep and fatigue drugs can modify the perception of fatigue for some pilots and had negative effects in aviation (Mohler, 1966). These studies on the effectiveness of pharmacological interventions have been included primarily because some of these medicines are appropriate for military aviation. However, pilots need to be aware of the risks of using these pharmacologic fatigue countermeasures, which has both disadvantages and advantages related to their effectiveness, abuse potential and side effects in the aviation operations.

3.4 Summary

In summary, no matter how advanced the aircraft, people remain at the heart of the system in aviation (Dinges, 2008). Given that job demands are likely to increase, pilots and management must be prepared to effectively control fatigue to sustain productivity, safety and personal well-being. There are scientifically-valid techniques to combat pilot fatigue within the aviation community. The implementation of napping, caffeine use and having good sleep habits have been recommended in various studies (Gregory et al., 2010). However, specific fatigue countermeasures must be tailored for individual pilots and their work situations (Caldwell, 2005). Individual pilots should consider the benefits and risks of each fatigue countermeasure before making a decision on which countermeasure is to be used. This process can help to minimise pilot fatigue risks associated with current and future aviation operations.

Chapter Four:Energy Drink Consumption

4.1 Introduction

A limited study can be found on consumption of energy drinks among student pilots; however, a vast body of research has been conducted in college student population during recent years. Consuming energy drinks has been a popular practice among them (Arria et al., 2011).

A study by Malinauskas, Aeby, Overton, Carpenter-Aeby, and Barber-Heidal (2007) examined energy drink consumption in 496 students from a public U.S university. The results indicated that 51% of the students consumed one energy drink each month on average. They found that 67% of the students consumed energy drinks for insufficient sleep, 65% for “to increase energy" (p. 35) and 54% for “to drink with alcohol while partying” (p. 35). In addition, 29% of students experienced weekly jolt and crash episodes, 22% had headaches and 19% experienced heart palpitations after consuming energy drinks.

Arria et al. (2011) conducted a longitudinal study that examined energy drink consumption among 1097 fourth-year college students. The results indicated 66% of the students consumed energy drinks. They found that 53% of the students were low-frequency energy drink users that consisted of occasional and monthly users, and 13% were high-frequency users that consisted of weekly and daily users. The results indicated that Red Bull energy drink was the most consumed and most common energy drink amongst all brands of energy drinks. The findings also suggested that 82% of the students consumed at least one can of Red Bull energy drink, 34% consumed Monster energy drink and 18.4% consumed Rock Star energy drink in the past twelve months. Cartwright (2013) suggested the individuals who consumed energy drinks on a regular basis would be prone to physiological and psychological changes that might affect their performance outcomes. Some researchers have identified moderate positive effects of energy drink consumption on both physical and cognitive performance among young adults (Alford et al., 2001; Horne & Reyner, 2001; Reyner & Horne, 2002; Warburton, Bersellini, & Sweeney, 2001).

4.2 Effect of Energy Drink Consumption on Physical Performance

Geiss, Jester, Falke, Hamm, and Waag (1994) investigated the effects of Red Bull energy drink consumption on the physical performance of ten male athletes. Each athlete completed three cycling trials and blood samples were extracted every 15 minutes during the experiment. The findings suggested that there was a significant increase in athletes' performance and a significantly prolonged endurance after consuming Red Bull energy drink. These were also supported by other results, such as lower heart rates and catecholamine concentrations.

Similarly, Forbes et al. (2007) confirmed the positive effects of Red Bull energy drink consumption on muscle strength, endurance and anaerobic power among 15 healthy adults. The findings suggested that total repetitions over three sets of bench press were significantly greater in the Red Bull energy drink group than in the placebo group. However, there were no significant differences in peak power, average power and blood lactate concentration between Red Bull energy drink and placebo group during cycling tests. The results indicated that Red Bull energy drink consumption had no effect on anaerobic power measures. It only enhanced upper body muscle endurance.

In contrast, Ragsdale et al. (2010) investigated the effects of Red Bull energy drink consumption on cardiovascular and neurologic functions among 68 university students. The findings suggested that there were no significant differences in the cardiovascular parameters assessments of the students in Red Bull energy drink group compared to the assessments of the students in the placebo group. The same results were found in blood pressures and heart rates. However, there was a trend that students in the Red Bull energy drink group negated the increase in blood pressure during the physical stressor tests. Additionally, they suggested that the consumption of a single can of 250ml Red Bull energy drink could increase the relaxation and pain tolerance levels.

4.3 Effects of Energy Drink Consumption on Cognition and Mood

Alford et al. (2001) examined the effects of energy drink consumption in three studies among 36 participants. The findings suggested that the consumption of Red Bull energy drinks significantly improved mental performance, choice reaction time, concentration, memory and alertness.

In a similar study, Smit and Rogers (2002) examined the effects of energy drink consumption on the mood and mental performance among 23 adults. Participants were assessed by mood questionnaires and cognitive performance measures. The results indicated that the participants in the energy drinks group performed significantly better in rapid visual information processing and had significantly higher scores in mood questionnaires compared to the participants in the water group. In addition, the findings suggested that energy drinks were more thirst quenching than the water.

Kennedy and Scholey (2004) examined the effects of energy drink consumption on the extended cognitive demanding tasks performance. The results indicated that there were improvements in accuracy of rapid visual information processing, vigilance and mental fatigue levels. Similarly, a double-blind crossover study was conducted to investigate the effects of Red Bull energy drink consumption on cognition and mood in ten young adults (Seidl, Peyrl, Nicham, & Hauser, 2000). Auditory event-related potential recording, d2 test[12] and the Basler Befindlichkeit questionnaire[13] were administered to measure motor reaction time, attention capacity and mood status. The findings suggested that participants in the Red Bull energy drink group had significant improvements in the motor reaction time and cognitive performance with higher scores of attention in a stressful situation. Additionally, the findings suggested that there were significant declines in the total scores of well-being, vitality, vigilance and social outgoingness for participants in the placebo group.

4.4 Effects of Caffeine

Caffeine is the most widely studied energy drink ingredient (Lohi, 2007). Loke (1988) exanimated the effects of caffeine on memory and mood in 95 healthy undergraduates, who were randomly assigned to one of three caffeine dose conditions: 0mg, 200mg, and 400mg. They were assessed in five tasks: “mood evaluation; cancellation; multiple-trial immediate free recall; delayed free recall and drug guessing” (p. 368).The findings

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[12] d2: a speed and power test that measures attention capacity in a stressful situation (Seidl et al., 2000).

[13] Basler Befindlichkeit questionnaire: a standard test for assessing mood in terms of life quality and emotional well-being (Seidl et al., 2000).

suggested that there was a significant dose-dependency among the undergraduates with increased in nervousness and decreased in relaxation. In particular, the undergraduates in the 400mg caffeine dose group experienced “more tenseness, nervousness, anxiousness, high-strung, restlessness, less calmness and fatigue” (p. 369) than of those in 0mg and 200 mg caffeine groups. Glade (2010) reviewed a large number of scientific literature on the beneficial effects of caffeine on human physiological systems and listed the following results when caffeine was consumed moderately:

1. It increases energy availability;
2. It increases daily energy expenditure;
3. It decreases fatigue;
4. It decreases the sense of effort associated with physical activity;
5. It enhances physical performance;
6. It enhances motor performance;
7. It enhances cognitive performance;
8. It increases alertness, wakefulness and feeling of energy;
9. It decreases mental fatigue;
10. It quickens reactions;
11. It increases the accuracy of reactions;
12. It increases the ability to concentrate and focus attention;
13. It enhances short-term memory;
14. It increases the ability to solve problems requiring reasoning;
15. It increases the ability to make correct decision;
16. It enhances cognitive functioning capabilities and neuromuscular coordination;
17. It is safe to healthy non-pregnant adults (p. 932-p. 938).

Caffeine has been used as a countermeasure against fatigue in military and commercial operations. However, the results can be conflicting. For example, Leino et al. (2007) conducted a double-blind study examining the effects of caffeine on the simulator flight performance in 13 Finnish male military pilots. Participants were assessed after 37 hours of sleep deprivation. The results indicated that the participants in the caffeine group indicated no difference in overall flight performance compared to those in the placebo group. In addition, the findings suggested that the 200mg of caffeine group indicated no significant effect on performance. They found that the young pilots were more resistant to the effect of sleep deprivation and they flew well even they were tired. However, Leino et al. (2007) did not agree with the use of caffeine pills in the military flight operations, as the findings suggested that overconfidence (decreased self-criticism) played a negative role among some pilots in the caffeine group, which might lead to a flight safety issue.

Riesenhuber, Boehm, Posch, and Aufricht (2006) examined the diuretic effect of caffeine in the Red Bull energy drinks among twelve healthy males. Participants were assessed by their urinary concentration tests. The findings suggested that diuretic and natriuretic effect of Red Bull energy drinks were mainly contributed by caffeine. Apart from having these side effects, caffeine users can get a rebound headache if they do not get caffeine. However, high doses of caffeine can also be dangerous (Cartwright, 2013). Unfortunately, no restrictions on energy drink consumption can make them unsafe if too much of energy drinks were consumed in one sitting. For instance, sudden cardiac death, Tachycardia, increased blood pressure, increased metabolic activity, dehydration from diuresis, insomnia, aggression and anxiety have been linked with high doses of caffeine (Dórea & da Costa, 2005).

4.5 Energy Drink, Alcohol and Drug Use

Multiple studies have suggested that there is a correlation between chronic energy drink consumption and alcohol and illicit drug use (Arria et al., 2011; Reissig, Strain, & Griffiths, 2009). Arria et al. (2010) observed a link between energy drink consumption and alcohol use in their study. The findings suggested that weekly or daily consumption of energy drink was strongly associated with alcohol dependence in college students. Additionally, they suggested that college students who frequently consumed energy drinks were more likely to be the target population for alcohol prevention.

Berger, Fendrich, Chen, Arria, and Cisler (2011) conducted a community-based survey examining the relationships of energy drink consumption with and without alcohol among 946 adults aged 19 to 92. The results indicated that participants in the mid-life age group (30 to 54) were more prevalent to consume energy drinks. Caucasian and young participants were likely to consume energy drinks with alcohol compared to other energy drink users. The higher household incomes (US$60,000+) group was more likely to consume energy drinks with alcohol. They found that alcohol energy drink users were more likely to become hazardous drinkers.

Arria et al. (2010) investigated the prevalence of energy drink consumption and its associations with drug use among 1060 undergraduates from a public U.S university. The results indicated that 25% of the undergraduates were energy drink users and 75% were non-energy drink users. The findings suggested that energy drink users had higher percentages in tobacco, marijuana, cocaine, and prescription stimulants use compared to non-energy drink users in drug use. The findings also suggested that a high risk for substance abuse problems amongst energy drink users.

4.6 Energy Drinks and Seizures

Iyadurai and Chung (2007) investigated four cases of individuals who have been brought to the emergency room due to seizure occurrences on multiple occasions after consuming energy drinks. They were males and females, ranging from 19 to 26 years of age. The findings suggested that none of them had any histories of febrile seizures or affected by seizure-provoking factors, such as sleep deprivation, excess caffeine intake, and illicit drugs. Those patients did not experience any recurrent seizures after being instructed to abstain from consuming energy drinks. The results suggested the common ingredients such as caffeine, taurine and guarana could be the direct cause of seizures amongst young energy drink users.

4.7 Summary

In summary, these studies have demonstrated that the consumption of energy drinks can affect physical, mood and cognitive performance in the general population (Arria et al., 2010). This chapter suggested the positive and negative effects when consuming energy drinks among young adults and university students. It has also demonstrated negative relationships between energy drink consumption, alcohol, drug uses and seizure occurrence.

Summary of Literature Review—Chapter Two, Three and Four

These three chapters of literature reviews have explored three areas: fatigue, fatigue countermeasures and energy drink consumption. It focused on the importance of fatigue awareness, its effects and techniques to mitigate fatigue in the aviation community. The case was made for a comprehensive understanding of fatigue and its countermeasures in two stages. First, identifying fatigue variables which can possibly influence pilot performance. Understanding the causes and effects of fatigue can provide more effective ways to adopting fatigue countermeasures. In the second stage, the importance of learning certain strategies to minimise fatigue among pilots was discussed. It has been suggested that more sleep during off-duty periods is one of the most important fatigue countermeasures.

Some benefits and risks associated with energy drink consumption were discussed. It is further suggested that the interaction between fatigue and energy drink consumption can be affected by the conditions under which the interaction takes place. Good fatigue management skills are thought to foster a safe learning and training environment and culture. While poor fatigue management skills create risk that jeopardises personal safety and the aviation community’s future growth.

The specific research questions generated by the study are:

1. What fatigue patterns do student pilots exhibit at pre-flight and post-flight?
2. What sleep patterns do student pilots exhibit at pre-flight?
3. What energy drink consumption patterns do student pilots exhibit in general?
4. What fatigue countermeasures do student pilots use?

5. How do some pre-flight fatigue variables (e.g., time of the day, age, gender, BMI, flying experience, flight duration, treatments, sleep, meal consumed, pre-flight alertness and fatigue scores) influence the post-flight fatigue test?
6. How does fatigue influence the student pilot performance levels at pre-flight and post-flight?
7. How does Red Bull energy drink consumption influence the student pilot fatigue levels?

Chapter Five:Methodology

5.1 Participants

A total of 142 student pilots completed and returned questionnaires. Student pilots were from the following four Flight Training Organisations (FTOs) in the North Island of New Zealand: Manawatu Flight Training Centre, Fielding; Air Hawke's Bay Flight Training Centre, Hastings; Massey University, Palmerston North; CTC Wings, Hamilton. The selection of the FTO from each location was dependent on the timing and availability of student pilots for testing since it was necessary to make prior arrangements and schedule the research. The CEOs, the CFIs (Chief Flight Instructors), and the Heads of Training from these FTOs were contracted. Emails and hand-outs were sent (see Appendix B & Appendix C). They all pledged support for this study, and dates were arranged to conduct the research at each FTO.

Table 5.1 Gender and FTOs

Gender and FTOs	Participants *n*	Invalid *n*	Valid *n*
Gender			
Male	131	27	104
Female	11	5	6
FTOs			
Manawatu Flight Training Centre	19	3	16
Air Hawke's Bay Flight Training Centre	20	3	17
Massey University	31	6	25
CTC Wings	72	20	52
Total	142	32	110

Participation in this study was voluntary, student pilots could terminate their participation at any time; however, no one chose to do so. Table 5.1 presents gender, FTOs and the number of participants, including valid and invalid data. Thirty two questionnaires were deemed invalid for a variety of reasons. Three factors contributed to this, flight cancellations (22.5%), medication use (6.3%) and incomplete data (1.4%). Flight cancellations were mainly due to poor and deteriorating weather conditions, weather beyond personal minimum for flying, and aircraft unavailability. The following medications were used by participants: Thyroxine, Panadol, Cilazapril, Metoprolol, Cerelle, Antihistamine, and Asthma Inhalers. Thus, the final sample of 110 questionnaires was analysed excluding 32 individuals.

5.2 Experimental Design and Treatments

An applied Quasi-experiment (a mixed experimental design) was employed in this study. There was one between-subjects variable (with 2 levels: water treatment group and Red Bull treatment group) and one within-subjects variable (with 2 levels: pre-flight test and post-flight test). Participants were tested twice, ranging from one to three hours apart (it was dependent on the flight duration) within the same day. The two experimental treatments were:

1. Red Bull Energy Drinks	250ml
2. Water	250ml

Each can of Red Bull energy drink contained carbonated water, sucrose (21.50g), glucose (5.25g), taurine (1,000mg), glucuronolactone (600mg), caffeine (80mg), inositol (50mg), vitamins (niacin, panthenol, B6, B12), citric acid, flavours, colour (caramel, riboflavin) (Alford et al., 2001).

Bottled New Zealand spring water was used as water treatment. It was administrated as a control to regulate the possible effect of the differences in liquid volume and possible effect of feeling refreshed when drinking. Water treatment was used for eliminating possible fatigue caused by dehydration. The volume for the water was 250ml, which was equivalent to a standard can of Red Bull energy drink. Energy drinks were not given in proportion to body weight, but as a fixed amount similar to the amount people would typically consume. There were no caffeine consumption restrictions on testing days; however, the number of caffeinated drinks was recorded by the participants in the pre-flight fatigue countermeasures section.

5.3 Test Instruments

The questionnaire was a locally-constructed instrument consisting of five sections (see Table 5.2). Its content was similar to previous studies in relation to pilot fatigue, sleep and energy drink consumption (Bliss & Depperschmidt, 2011; Buysse, Reynolds III, Monk, Berman, & Kupfer, 1989; Chalder et al., 1993; Michielsen, De Vries, & Van Heck, 2003).

The arrangement of these sections was necessary to fit within the time constraints of the student pilots and their flight operations. In addition, these questions were aimed at establishing relationships between pilot fatigue, sleep and energy drink consumption. There were a total of 74 questions and several items included multiple sub-questions. Thus, there were actually a total of 154 possible responses from each questionnaire.

Table 5.2 Questionnaire Layouts

No. of Sections	Name of Each Section	No. of Questions per Section
Section One	Pre-Flight Fatigue	14 Questions
Section Two	Post-Flight Fatigue	20 Questions
Section Three	Demographics	14 Questions
Section Four	Sleep and Fatigue	12 Questions
Section Five	Energy Drink Consumption	14 Questions

5.3.1 Demographic Questions

Twelve demographic variables were investigated, including age, weight, height, ethnic group, total flight time in the logbook, gender, smoking habit, pregnancy, medication, employment, medical certificate and aviation theoretical examinations status. BMI was calculated. The first five variables were presented in short answer format and the reminder had a Yes/No option. In addition, age was categorised into three groups (17–19, 20–29, and 30–39).

5.3.2 The Measurement of General Sleep and Fatigue

The Pittsburgh Sleep Quality Index (Buysse et al., 1989) was used for measuring sleep qualities among participants. Its components included sleep duration (during training and off training), sleep latency, sleep disturbance and overall sleep quality (day and night).

In addition, sleep duration was calculated and categorised into four groups (≤6.0, 6.1–7.0, 7.1–8.0, and ≥8.1) and sleep latency were categorised into four groups (≤15min, 16–30 min, 31–59min and ≥60min). Sleep disturbance was rated by the number of wakes during a typical night sleep (ranging from 1 to 5 or more). Overall sleep quality was rated from ranging 1 for poor to 5 for excellent.

5.3.3 The Measurement of Energy Drink Consumption

Participants' energy drink consumption were measured by four questions, which were similar to an influential student pilots and energy drink consumption study (Bliss & Depperschmidt, 2011).

1. *Which of the following brand of energy drink have you consumed in the past 12 months?*
2. *How many energy drinks do you consume per week?*
3. *Have you consumed energy drink on the same day that you piloted an aircraft?*
4. *In what circumstance do you consume energy drink?*

5.3.4 The Measurement of Pre-Flight Items

Five general pre-flight variables were investigated, including aircraft type, cockpit display type, flight lesson, sleep hours in the past 24 hours and number of meals consumed. These five variables were presented in short answer format.

5.3.5 The Measurement of In-Flight Pilot Performance

The following eleven statements were used to measure participants' in-flight performance levels, which were similar to a previous pilot fatigue study (Michielsen, De Vries, & Van Heck, 2003). A seven point Likert scale (1: strongly disagree to 7: strongly agree) was used to rate these statements. In addition, flight duration was categorised into five groups (<1 hr; 1 hr; 1.5 hrs; 2 hrs and 2.5 hrs).

1. *There was a high workload throughout the flight.*
2. *I found it easy to recall important points and concepts relating to the training flight.*
3. *My performance gradually decreased throughout the flight.*
4. *My performance sharply decreased near the end of the flight.*
5. *I would be able to perform at the same level of proficiency on another similar training flight to be commenced now.*
6. *I would be able to perform at a higher level on another similar training flight to be commenced now.*
7. *I became easily distracted at times near the end of the flight.*
8. *I made small mistakes or forgot things at the start of the flight.*
9. *I made small mistakes or forgot things near at the end of the flight.*
10. *My flying ability improved over the course of the flight.*
11. *I was able to maintain a focus on the requirements of the training flight throughout its duration.*

5.3.6 The Measurement of In-Flight Pilot Fatigue

Four questions were used to measure participants' in-flight fatigue levels. These questions were similar to a previous pilot fatigue study (Michielsen, De Vries, & Van Heck, 2003).

1. *How manageable is it to remain alert during a usual flight lesson?*
2. *How many times have you fallen asleep in the cockpit while flying?*
3. *In what way has fatigue affected your flight performance?*
4. *When your flight performance is affected by fatigue, which phase of flight performance is affected?*

5.3.7 The Measurement of Pre-Flight Pilot Fatigue

Participants' pre-flight fatigue levels were measured by six items, which were similar to previous fatigue studies conducted by Chalder et al. (1993); Michielsen, De Vries, and Van Heck (2003); and Michielsen, De Vries, Van Heck, Van de Vijver, and Sijtsma (2004). These fatigue items were classified into two fatigue symptoms (mental and physical) for further analysis according (see Table 5.3). A seven point Likert scale (1: strongly disagree to 7: strongly agree) was used to rate each item.

Table 5.3 Pre-Flight Fatigue Items

Pre-flight	Items	Symptoms
Pre Q1	Mentally, I am well prepared to undergo the flight	Mental
Pre Q2	I feel energetic	Physical
Pre Q3	I feel more forgetful than normal	Mental
Pre Q4	I can concentrate very well	Mental
Pre Q5	I have an overall feelings of tiredness	Physical
Pre Q6	I feel mentally exhausted	Mental

5.3.8 The Measurement of Post-Flight Pilot Fatigue

Participants' post-flight fatigue levels were measured by six items (see Table 5.4), which were similar to fatigue studies conducted by Chalder et al. (1993); Michielsen, De Vries, and Van Heck (2003); and Michielsen, De Vries, Van Heck, Van de Vijver, and Sijtsma (2004). Post-flight fatigue items were classified and rated in the same way as pre-fatigue items.

Table 5.4 Post-Flight Fatigue Items

Post-flight	Items	Symptoms
Post Q1	I am pleased with the outcome of the flight	Mental
Post Q2	I was well prepared to undergo the flight	Mental
Post Q3	I find it difficult to concentrate	Mental
Post Q4	I can think clearly	Mental
Post Q5	I feel relaxed	Physical
Post Q6	I feel worn out	Physical

5.3.9 The Measurement of Cognitive Performance

Participants' cognitive and vigilance levels were measured by using a version of the psychomotor vigilance task (PVT), which has been investigated and validated by Wilkinson and Houghton (1982) and Dinges and Powell (1985).This test was presented and implemented with the open-source Psychology Experiment Building Language framework (Mueller & Piper, 2013, Version 0.13), and is known as the PEBL Perceptual Vigilance Task (PPVT). It has become a standard laboratory tool to measure sustained attention, reaction time in a variety of experimental conditions (Loh, Lamond, Dorrian, Roach, & Dawson, 2004; Mueller & Piper, 2013). For 121 consecutive trials, a stimulus (a red dot) was presented in the middle of the computer screen in a variable interval of randomised delays ranging from 1,000 to 10,000 milliseconds (see Figure 5.1).

Participants were required to focus on a fixation point and wait for a stimulus, then quickly press the spacebar as soon as the red dot appeared on the screen. PPVT was set at a standard duration of ten minutes. Laptop computers were placed on separate desks against the wall in a room for PPVT tests (see Figure 5.2).

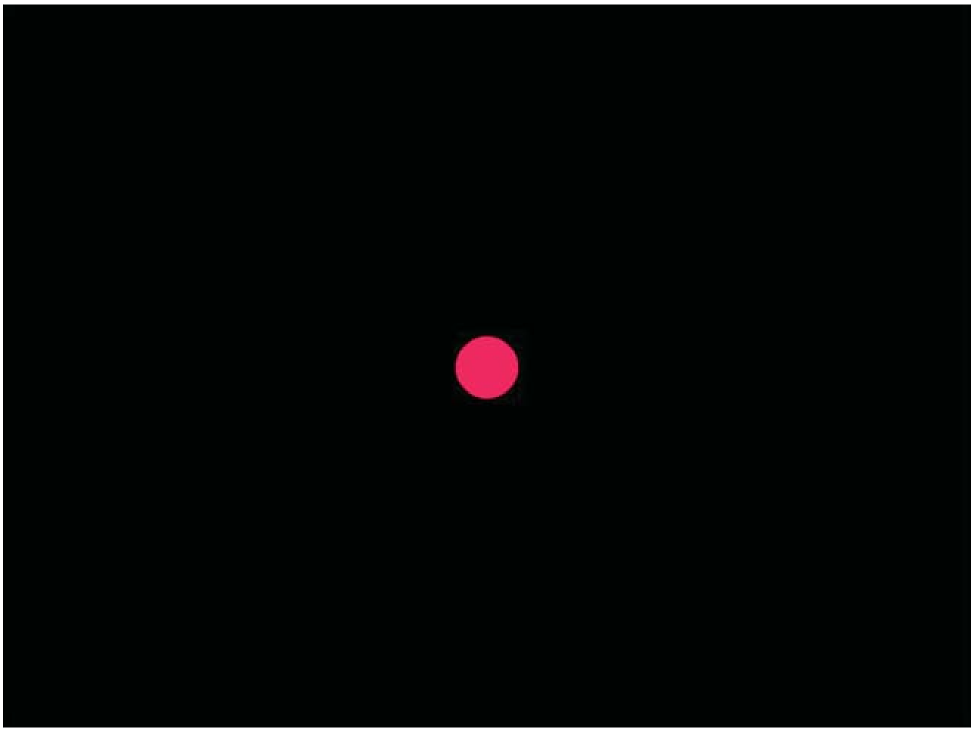


Figure 5.1 PPVT Screen

PPVT (2010).Retrieved from http://sourceforge.net/apps/mediawiki/pebl/index.php?title=File:Ppvt.jpg.

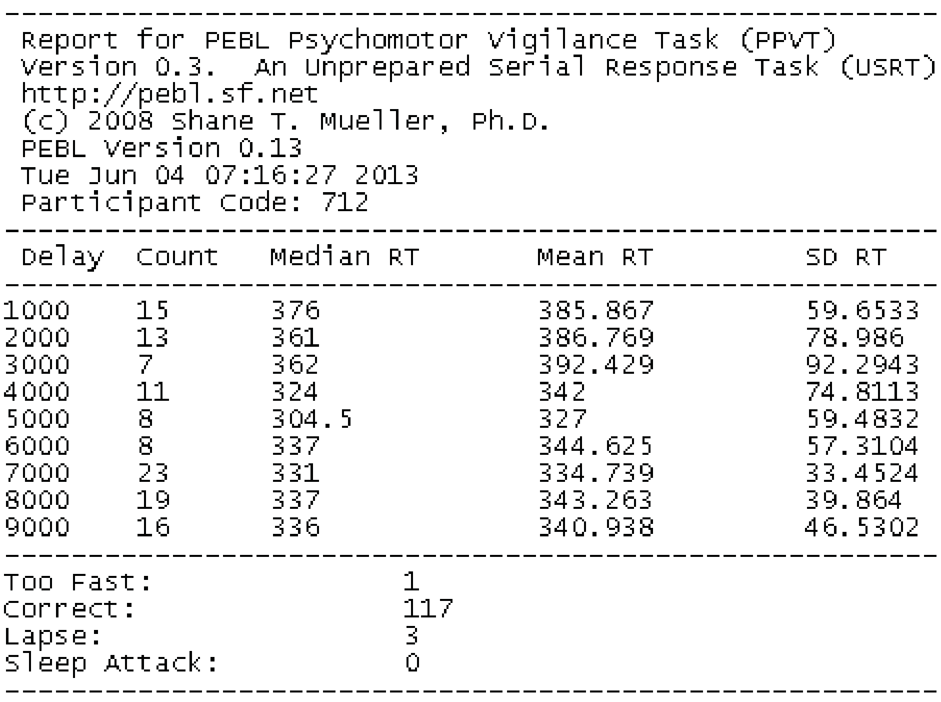
Figure 5.2 Testing Station

The majority of the participants did not get their PPVT results; only two participants enquired about theirs, and were informed of the results after completing their questionnaires. All participants were instructed to read and follow the PPVT testing instructions which were displayed on the computer screen. At the end of each ten-minute PPVT trial, a text file report of the result was created (see Figure 5.3).The text file recorded the following data:

1. Time and Date;
2. Participant Code (e.g.,712);
3. Delay[14] (e.g.,1,000ms);
4. Count[15] (e.g.,15);
5. Mean Reaction Time (RT) at each interval delay (e.g., 385.867ms);
6. Median RT at each interval delay (e.g.,376ms);
7. Standard Deviation (SD) RT at each interval delay (e.g., 59.6533ms);
8. Too Fast[16] (e.g.,1);
9. Correct (e.g.,117);
10. Lapse[17] (e.g.,3);
11. Sleep Attack[18] (e.g., 0).

---

[14] Delay: interval of delays ranging from 1,000 to 10,000 milliseconds (Mueller & Piper, 2013).
[15] Count: number of stimuli (Mueller & Piper, 2013).
[16] Too Fast: reacting before the stimuli is presented (Mueller & Piper, 2013).
[17] Lapse: taking more than 500ms to react (Mueller & Piper, 2013).
[18] Sleep Attack: taking more than 30s to react (Mueller & Piper, 2013).



```
--------------------------------------------------------
 Report for PEBL Psychomotor Vigilance Task (PPVT)
 Version 0.3.  An Unprepared Serial Response Task (USRT)
 http://pebl.sf.net
 (c) 2008 Shane T. Mueller, Ph.D.
 PEBL Version 0.13
 Tue Jun 04 07:16:27 2013
 Participant Code: 712
--------------------------------------------------------
 Delay  Count   Median RT       Mean RT         SD RT
--------------------------------------------------------
1000    15      376             385.867         59.6533
2000    13      361             386.769         78.986
3000    7       362             392.429         92.2943
4000    11      324             342             74.8113
5000    8       304.5           327             59.4832
6000    8       337             344.625         57.3104
7000    23      331             334.739         33.4524
8000    19      337             343.263         39.864
9000    16      336             340.938         46.5302
--------------------------------------------------------
Too Fast:               1
Correct:                117
Lapse:                  3
Sleep Attack:           0
--------------------------------------------------------
```

Figure 5.3 PPVT Report

PPVT Report (2013). Retrieved from http://pebl.sf.net.

Table 5.5 The Karolinska Sleep Scale

	The Karolinska Sleep Scale
1	Extremely Alert
2	Very Alert
3	Alert
4	Rather Alert
5	Neither Alert Nor Sleepy
6	Some Signs of Sleepiness
7	Sleepy, No Effort to Stay Awake
8	Sleepy, Some Effort to Stay Awake
9	Very Sleepy, Great Effort to Keep Awake

5.3.10 The Measurement of Sleepiness and Alertness

Participants' sleepiness and alertness levels were measured by using the Karolinska Sleepiness Scale (KSS), a nine point Likert scale (see Table 5.5). KSS has been validated and recognised as a standard tool for assessing sleepiness and alertness in aviation and various research scenarios in both laboratory and field settings (Akerstedt & Gillberg, 1990; Eriksen, Akerstedt, & Nilsson, 2006; Kaida et al., 2006). KSS was used in the pre-flight test and post-flight test.

5.4 Recruitment

Two methods were employed for recruiting potential participants in this study: face-to-face approach and prior-arrangement by FTOs. Face-to-face approach, referred to student pilots being approached and asked whether they would like to take part in a study. The majority of pilots who were approached indicated a great interest in the study and agreed to participate. Only two student pilots refused to take part. Fifty per cent of the participants were recruited by using this method. The second method was reliant on the cooperation of the FTOs operational staff. Information such as time and date of student pilots' scheduled flights, and the number of student pilots willing to participate was provided by the FTOs operational staff. Regardless of which method was used during the recruitment, all participants were asked for verbal consent prior to their participation in this study and advised to report to a designated testing room, 30 minutes prior to their flights.

5.5 Procedure

The procedure consisted of two phases: pre-flight test and post-flight test. During pre-flight test, participants were given the questionnaire, briefing and instructions. An old New Zealand Florin coin was tossed to determine at random of what type of drink the participants had to consume.

All participants were randomly given either bottled water or Red Bull energy drinks at room temperature at the beginning of the pre-flight test which allowed time for absorption. Pairs of participants were given the same time slot. They were tested simultaneously at individual stations in order to utilise testing time more effectively. Sometimes participants were tested alone due to the limited number of student pilots during certain time of the day.

Participants were then asked to complete section one of the questionnaire before taking the first PPVT test on the computer. The allocated time to complete the pre-flight test phase questionnaire was 15 minutes. Once the first PPVT test was completed, the approximate returning time from the flight was recorded from each participant. In addition, post-flight test time slot was allocated and advised. Participants proceeded on their scheduled flights in accordance with their flight training programme.

During post-flight test phase, participants were asked to complete section two of the questionnaire. The allocated time was five minutes. Participants then completed the second PPVT test on the same computer which they had been previously tested on. After the second PPVT test, participants completed section three, four and five of the questionnaire. The total allocated time to complete both tests was 40 minutes. On average, participants completed both tests (pre-flight test and post-flight test) in 39 minutes without affecting their flight schedules. The testing schedule is presented in Table 5.6.

Table 5.6 Testing Schedule

Items	Duration (minutes)
Pre-Flight Test Phase	
Treatment	2
Section One + Pre-Flight KSS	3
Pre-Flight PPVT Test	10
Post-Flight Test Phase	
Section Two + Post-Flight KSS	5
Post-Flight PPVT Test	10
Section Three	3
Section Four	3
Section Five	3
Total	39

5.6 Statistical Considerations

All statistical analyses were performed using the statistical package SPSS, with alpha set at .05. Descriptive characteristics were summarised using *means* and *standard deviations* for continuous variables, and counts (*n*) for categorical variables. One-way analysis of variance (ANOVA) tests and Chi-square tests were used to determine differences for continuous variables and categorical variables respectively.

Mixed model analysis of variance (ANOVA) tests with 2 (treatment groups: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) as main factors were used to determine any differences between the treatment groups for fatigue and performance levels. Significant main effects of interactions were subjected to the Tukey post hoc tests and Bonferroni correction.

Additionally, Principle Component Analysis (PCA) was used to aggregate the responses in the fatigue sections of the questionnaire into a single numerical measure, to simplify the analysis. PCA results were used as variables for further analysis. Standard multiple regression was conducted. It was chosen as an appropriate measure for predicting the effect of several pre-flight fatigue independent variables on a post-flight fatigue dependent variable.

5.7 Summary

In summary, the questionnaire had five sections, including the pre-flight and the post-flight fatigue items, demographics items, sleep and fatigue items, and energy drink consumption items. In addition, KSS and PPVT were administered in the pre-flight and post-flight test as subjective and objective measurements of student pilot fatigue and performance levels.

Chapter Six:Results and Analysis

6.1 Demographic Results

110 student pilots (6 female and 104 male) completed their questionnaires and solo flights, with a mean age of 22.45 (±3.7) years and a mean body mass index of 24.7 (±3.6) obesipascals (kg/m^2), see Table 6.1. All participants reported no medical, psychiatric, or neurological issues, and all participants held valid Class One Medical Certificates. The sample characteristics were derived from the demographic section of the questionnaire, which was answered by participants after their flights. This was due to time constraints imposed on participants by their respective flight operations.

Table 6.1 presents the demographic characteristics of the participants and demographic characteristics between the treatment groups. A Chi-square test was conducted to analyse the characteristics of categorical data between two treatment groups. The results indicated that the distribution of participants in the treatment groups did not differ by age, χ^2 (2, N = 110) = 5.25, p = .07; gender, χ^2 (1, N = 110) = 2.82, p = .09; experience, χ^2 (6, N = 110) = 4.61, p = .59; BMI, χ^2 (2, N = 110) = 2.37, p = .31; ethnic groups, χ^2 (7, N = 110) = 7.53, p = .38; job status, χ^2 (3, N = 110) = 6.65, p = .08 and medical status, χ^2 (2, N = 110) = .55, p = .76.

Table 6.1 Demographic Characteristic

Characteristics	All, *N*=110 *n*	Water, *N*=55 *n*	Red Bull, *N*=55 *n*	*df*	χ^2	*p*
Age				2	5.25	.07
17–19	21	6	15			
20–29	84	47	37			
30–39	5	2	3			
Gender				1	2.82	.09
Male	104	50	54			
Female	6	5	1			
Experience (hours)				6	4.61	.59
<25	8	6	2			
25–49	24	12	12			
50–99	29	14	15			
100–149	14	5	9			
150–199	13	8	5			
200–249	7	4	3			
≥250	5	6	9			
Body Mass Index (kg/m^2)				2	2.37	.31
Normal (18.5–24.9)	64	35	29			
Overweight (25.0–29.9)	41	18	23			
Obese (≥30.0)	5	2	3			
Ethnic				7	7.53	.38
New Zealand European	50	25	25			
UK British	30	14	16			
Indian	14	8	6			
Chinese	9	5	4			
European	4	0	4			
Korean	1	1	0			
Thai	1	1	0			
Vietnamese	1	1	0			
Cigarette Smoking Status				1	.00	1
No	100	50	50			
Yes	10	5	5			
Job status				3	6.65	.08
Full-time Job (≥35hr per week)	1	1	0			
Part-time Job (≤20hr per week)	5	5	0			
Part-time Job (≤10hr per week)	7	4	3			
No Job	97	45	52			
Medical Status				2	.55	.76
NZ Class One	75	37	38			
UK Class One	27	13	14			
HK Class One	8	5	3			

Table 6.2 presents a one-way ANOVA of the main characteristics between the treatment groups. A one-way ANOVA test was conducted and results indicated no significant differences between the treatment groups by age *F* (1,108) = 1.07, *p* = .30; BMI, *F* (1,108) = 1.31, *p* = .26; time of day, *F* (1,108) = .25, *p* = .62; flying experience, *F* (1,108) = .12, *p* = .73; flight duration, *F* (1,108) = .06, *p* = .80 and sleep duration in the past 24 hours, *F* (1,108) = 2.32, *p* = .13.

Table 6.2 ANOVA of Age, BMI, Time, Experience, Duration and Sleep

Variables	All, *N*=110 *M* (*SD*)	Water, *N*=55 M (*SD*)	Red Bull, *N*=55 *M* (*SD*)	*df*	*F*	*p*
Age	22.45 (3.70)	22.82 (3.51)	22.09 (3.86)	1	1.07	.30
BMI	24.70 (3.60)	24.31 (3.02)	25.09 (4.10)	1	1.31	.26
Time	10:00 (2:29)	10:06 (2:19)	09:53 (2:20)	1	.25	.62
Experience	127.57 (116.15)	123.68 (118.57)	131.46 (114.65)	1	.12	.73
Duration	1.37 (.64)	1.36 (.63)	1.39 (.66)	1	.06	.80
Sleep	7.32 (1.39)	7.52 (1.44)	7.12 (1.31)	1	2.32	.13

Table 6.3 describes participants’ aviation theoretical experience between the treatment groups. Seventy one point eight per cent of the participants completed Private Pilot Licence (PPL) examinations. Forty nine point one per cent of the participants completed Commercial Pilot Licence (CPL) and Instrument Flight Rules (IFR) examinations. Twenty six point four per cent of the participants completed Airline Transport Pilot Licence (ATPL) theoretical examinations from their home countries. The distribution of participants in the treatment groups did not differ significantly in terms of their aviation theoretical experience.

Table 6.3 Aviation Theoretical Examinations

Theoretical Examinations	All, *N*=110 *n*	Water *N*=55 *n*	Red Bull *N*=55 *n*	*df*	χ^2	*p*
PPL						
Air Law	103	51	52	1	.15	.70
English Language Proficiency	83	41	42	1	.05	.83
Flight Radio Telephony	81	40	41	1	.05	.83
Human Factors	82	41	41	1	.00	1.00
Meteorology	79	39	40	1	.05	.83
Air Navigation and Flight Planning	79	39	40	1	.05	.83
Aircraft Technical Knowledge	79	39	40	1	.05	.83
CPL						
Air Law	66	32	34	1	.15	.70
Meteorology	67	32	35	1	.34	.56
Flight Navigation	66	32	34	1	.15	.70
General Aircraft Technical Knowledge	64	31	33	1	.15	.70
Principles of Flight	64	30	34	1	.60	.44
IFR						
Flight Navigation	59	27	32	1	.91	.34
Instruments and Navigation Aids	54	25	29	1	.58	.45
ATPL						
UK ATPL Examinations	21	9	12	1	.53	.47
HK ATPL Examinations	8	5	3	1	.54	.46

6.2 Pittsburgh Sleep Quality Components

A Chi-square test was conducted on Pittsburgh Sleep Quality components (see Table 6.4). The results indicated that the distribution of participants in the treatment groups had no significant differences by the following components: sleep duration in training, χ^2 (3, N = 110) = .62, p = .89; sleep duration off training, χ^2 (3, N = 110) = 5.64, p = .13; sleep latency, χ^2 (3, N = 110) = 6.17, p = .10; quality of sleep at night, χ^2 (3, N = 110) = 4.63, p = .20 and quality of sleep at day, χ^2 (4, N = 110) = 7.28, p = .12. In addition, no participants reported poor quality sleep at night. Forty five point five per cent of the participants reported that they generally fell asleep within 15 minutes and obtained more than eight hours of sleep each night in the training period.

Table 6.4 Pittsburgh Sleep Quality Components

Sleep Characteristics	All *N*=110 *n*	Water *N*=55 *n*	Red Bull *N*=55 *n*	*df*	χ^2	*p*
Sleep Duration (Training)				3	.62	.89
≤6.0 hrs	6	3	3			
6.1–7.0 hrs	15	7	8			
7.1–8.0 hrs	39	18	21			
≥8.1 hrs	50	27	23			
Sleep Duration (Off Training)				3	5.64	.13
≤6.0 hrs	3	3	*			
6.1–7.0 hrs	5	2	3			
7.1–8.0 hrs	16	5	11			
≥8.1 hrs	86	45	41			
Sleep Latency				3	6.17	.10
≤15 mins	50	28	22			
16–30 mins	46	20	26			
31–59 mins	8	2	6			
≥60 mins	6	5	1			
Sleep Quality at Night				3	4.63	.20
1 = Poor	*	*	*			
2 = Fair	11	6	5			
3 = Good	42	26	16			
4 = Very Good	38	15	23			
5 = Excellent	19	8	11			
Sleep Quality at Day				4	7.28	.12
1 = Poor	29	16	13			
2 = Fair	35	14	21			
3 = Good	28	14	14			
4 = Very Good	13	10	3			
5 = Excellent	5	1	4			

* = zero response

6.3 Energy Drink Consumption Results

Table 6.5 presents the results of some popular brands of energy drinks in the New Zealand market which were consumed by participants in the past twelve months. There were 216 responses received under "*select all that apply*". Red Bull energy drink was the most popular brand (38.4%) in all age groups. Age 20–29 group (75.9%) had a diverse experience in consuming different brands of energy drinks than other age groups. Age 30–39 (0.9%) only had a limited experience on consuming energy drinks.

Table 6.5 Energy Drink Brands

Brands	All, *N*=216 *n*	Age: 17–19 *N* = 50 *n*	Age: 20–29 *N* = 164 *n*	Age: 30–39 *N* = 2 *n*
Red Bull Energy Drink	83	16	65	2
V Vitalise Energy Drink	51	8	43	*
Monster Energy Drink	15	3	12	*
Lift Plus Energy Drink	26	10	16	*
Mother Energy Drink	14	3	11	*
Rock star Energy Drink	9	3	6	*
Demon Energy Drink	7	3	4	*
No's Energy Drink	4	2	2	*
Pure Energy Drink	2	1	1	*
Other brands	5	1	4	*

* = zero response.

The results for "*How many energy drinks do you consume per week?*" is presented in Table 6.6. Sixty eight point two per cent of the participants indicated that they did not consume any energy drinks in a week. Twenty eight point two per cent of the participants indicated that they consumed 1–3 of energy drinks per week. Participants in the age group 20–29 consumed more energy drinks per week than participants in other age groups. A Chi-square test indicated that there was a significant difference between the age groups in the number of energy drinks consumed in a week, χ^2 (6, N = 110) = 14.75, p = .02.

Table 6.6 Energy Drink Consumption Quantities

Quantities	All, N = 110 n	Age: 17–19 N = 21 n	Age: 20–29 N = 84 n	Age: 30–39 N = 5 n	df	χ^2	p
					6	14.75	.02
0 per week	75	9	61	5			
1–3 per week	31	9	22	*			
4–6 per week	3	2	1	*			
7–9 per week	1	1	*	*			

*= zero response.

Table 6.7 presents the results of the circumstances that participants had consumed energy drinks in the past. There were 175 responses received under “*select all that apply*”. Three common circumstances for participants to consume energy drinks were: “*I mix them with alcohol when I am party*” (22.9%), “*Study for exam/complete homework*” (18.3%) and “*I need more energy in general*” (17.1%). Three least common circumstances were “*sleep deprivation*” (5.7%), “*Piloting aircraft*” (2.9%) *and* “*Peer/Social pressure*” (1.7%). Other circumstances, such as sport activities, feeling thirsty and losing weights was also reported by some participants.

Table 6.7 Energy Drink Consumption Circumstances

Circumstances	All, N = 175 *n*	Age: 17–19 N = 33 *n*	Age: 20–29 N = 139 *n*	Age: 30–39 N = 3 *n*
Mixing it with Alcohol at a Party	40	7	31	2
Study for Exam/Complete Homework	32	5	27	*
Requiring More Energy in General	30	6	24	*
Others	28	7	21	*
Driving Automobile (extended period)	27	4	22	1
Sleep Deprivation	10	3	7	*
Piloting Aircraft (extended period)	5	1	4	*
Peer/Social Pressure	3	*	3	*

*= zero responses

Table 6.8 presents the results of how many cans or bottles of energy drinks that participants could consume daily without experiencing side effects (jolt and crash episodes, headaches, heart palpitations, etc.). There were 211 responses under "*select all that apply*". Energy drinks ranging from 473ml to 568ml (41.2%) were the most consumed by the participants without experiencing side effects. Energy drinks ranging from 330ml to 355ml (25.6%) were the least consumed. Thirty three point two per cent of the responses indicated that they could consume at least one can of 250ml energy drink without experiencing any side effects.

Table 6.9 presents the results of the question: "*Have you consumed energy drink on the same day that you piloted an aircraft?*" A Chi-square test indicated that there was a significant difference in the response to the question between the treatment groups, χ^2 (1, N = 110) = 4.45, p = .04.

Table 6.8 Energy Drink Consumption without Side Effects in Quantities/Volume

Volume	Quantities	All, *N* = 211 *n*
250ml	1	30
	2	22
	3	10
	4	6
	>4	2
330ml–355ml	1	28
	2	14
	3	9
	4	3
	>4	*
473ml–568ml	1	60
	2	25
	3	2
	4	*

*= zero response.

Table 6.9 Consumption of Energy Drink in the Same Day Piloted an Aircraft

	All, *N* = 110 *n*	Water, *N* = 55 *n*	Red Bull, *N* = 55 *n*	*df*	χ^2	*p*
				1	4.45	.04
Yes	61	25	36			
No	49	30	19			

6.3.1 Pre-Flight Perception of Energy Drink Consumption

6.3.1.1 The Treatment Groups

Table 6.10 presents a one-way ANOVA of the pre-flight perception of energy drink consumption between the treatment groups. The responses indicated that there was a significant difference between the treatment groups in terms of "*Chronic use of energy drinks can lead to other use of stimulants*", F (1,108) = 4.61, p = .03. The responses indicated that no significant difference between the treatment groups in terms of "*Energy drinks have no effect on short term memory*", F (1,108) = 2.03, p = .16.

6.3.1.2 The Energy Drink Users & Non-Users

Based on Table 6.6, 35 participants were classified as energy drink users, who consumed at least of one energy drink per week within the past 30 days. 75 participants were classified as non-users, who did not consume any energy drinks per week within the past 30 days. Table 6.11 presents the results of the pre-flight perception of energy drink consumption between the energy drink users and non-users. A one-way ANOVA was conducted to test any significant differences in the perception of common energy drink consumption side effects. The responses of the following items indicated that there were significant differences between the energy drink users and non-users in terms of "*Jolt and crash (no/low energy) episodes are typical after consumption of energy drinks*", F (1,108) = 16.89; $p < .001$; "*Heart palpitations (pounding or racing) are common after consuming energy drinks*", F (1,108) = 4.64; p = .03; "*Headaches are common after consuming energy drinks*", F (1,108) = 4.64, p = .01 and "*I feel effectively energised after consuming energy drinks*", F (1,108) = 4.45, p = .03.

6.3.1.3 The Flight Duration Groups

Table 6.12 presents a one-way ANOVA of the pre-flight perception of energy drink consumption between the flight duration groups. There was no evidence of any significant differences between the five flight duration groups and the responses to the pre-flight perception of energy drink consumption items. The Tukey post hoc tests and Bonferroni correction found no significant differences between them.

6.3.2 Post-Flight Perception of Energy Drink Consumption

6.3.2.1 The Treatment Groups

Table 6.13 presents a one-way ANOVA of the post-flight perception of energy drink consumption between the treatment groups. The responses indicated that the difference fell just short of significance between the treatment groups in terms of "*Student pilots should not consume an energy drink on same day they operate an aircraft*", *F* (1,108) = 3.24; *p* = .08.

6.3.2.2 The Energy Drink Users & Non-Users

Table 6.14 presents a one-way ANOVA of the post-flight perception of energy drink consumption between the energy drink users and non-users. The responses indicated there were no significant differences between the energy drink users and non-users in terms of "*Energy drinks have an effect on a student pilot's ability to pilot an aircraft*", *F* (1,108) = .03; *p* = .86 and "*Energy drinks are an effective and safe method to increase a student pilot's mental and physical performance*", *F* (1,108) = .56; *p* = .46. However, the responses indicated there was a significant difference between energy drink users and non-users in terms of "*Student pilots should not consume an energy drink on same day they operate an aircraft*", *F* (1,108) = 14.68; *p* < .001.

6.3.2.3 The Flight Duration Groups

Table 6.15 presents a one-way ANOVA of the post-flight perception of energy drink consumption between the flight duration groups. There was no evidence of any significant differences between the five flight duration groups and the responses to the post-flight perception of energy drink consumption items. The Tukey post hoc tests and Bonferroni correction found no significant differences between them.

Table 6.10 One-Way ANOVA of The Pre-Flight Energy Drink Perception (Th

Pre-Flight Energy Drinks Perception	Water *N* = 55 *M* (*SD*
Consumption of energy drinks is considered similar to consumption of coffee.	4.16 (1.6
Jolt and crash (no/low energy) episodes are typical after consumption of energy drinks.	4.60 (1.6
Headaches are common after consuming energy drinks.	3.71 (1.7
Heart palpitations (pounding or racing) are common after consuming energy drinks.	4.00 (1.6
Energy drinks have no effect on short term memory.	3.78 (1.7
Chronic use of energy drinks can lead to other use of stimulants.	4.24 (1.7
The consumption of energy drinks can be associated with risky or behaviour problem.	3.95 (1.6
I feel effectively energised after consuming energy drinks.	3.87 (1.5

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Table 6.11 One-Way ANOVA of The Pre-Flight Energy Drink Perception (The Energ

Pre-Flight Energy Drink Perception	Users (*N*=35) *M* (*SD*)
Consumption of energy drinks is considered similar to consumption of coffee.	4.46 (1.8
Jolt and crash (no/low energy) episodes are typical after consumption of energy drinks.	3.54 (1.8
Headaches are common after consuming energy drinks.	2.97 (1.7
Heart palpitations (pounding or racing) are common after consuming energy drinks.	3.54 (1.6
Energy drinks have no effect on short term memory.	4.23 (1.7
Chronic use of energy drinks can lead to other use of stimulants.	3.69 (2.0
The consumption of energy drinks can be associated with risky or behaviour problem.	3.74 (1.9
I feel effectively energised after consuming energy drinks.	4.46 (1.4

*= p<.001

Table 6.12 One-Way ANOVA of The Pre-Flight Energy Drink Perception (The F

	Flight Duration			
Pre-Flight Energy Drink Perception	<1 hr *N*=50 *M* (*SD*)	1 hr *N*=8 *M* (*SD*)	1.5 hrs *N*=16 *M* (*SD*)	2 hrs *N*=21 *M* (*SD*)
Consumption of energy drinks is considered similar to consumption of coffee.	4.24 (1.65)	4.88 (1.25)	3.63 (1.67)	4.29 (1.79)
Jolt and crash (no/low energy) episodes are typical after consumption of energy drinks.	4.24 (1.66)	5.13 (.64)	4.25 (1.92)	4.86 (1.88)
Headaches are common after consuming energy drinks.	3.46 (1.68)	2.88 (1.25)	3.38 (1.54)	3.57 (2.14)
Heart palpitations (pounding or racing) are common after consuming energy drinks.	4.08 (1.54)	3.75 (1.67)	3.63 (1.71)	4.57 (1.75)
Energy drinks have no effect on short term memory.	4.20 (1.63)	3.75 (1.58)	3.56 (1.83)	4.05 (1.77)
Chronic use of energy drinks can lead to other use of stimulants.	3.66 (1.86)	3.88 (1.13)	4.31 (2.09)	3.71 (1.83)
The consumption of energy drinks can be associated with risky or behaviour problem.	3.76 (1.72)	3.63 (1.19)	3.75 (1.69)	4.14 (1.91)
I feel effectively energised after consuming energy drinks.	4.06 (1.62)	4.00 (1.51)	3.38 (1.59)	4.43 (1.54)

Table 6.13 One-Way ANOVA of The Post-Flight Energy Drink Perception (Th

Post-Flight Energy Drink Perception	Water *N*=55 *M* (*SD*
Energy drinks have an effect on a student pilot’s ability to pilot an aircraft.	4.31 (1.6
Energy drinks are an effective and safe method to increase a student pilot’s mental and physical performance.	3.15 (1.5
Student pilots should not consume an energy drink on same day they operate an aircraft.	3.63 (1.5

Table 6.14 One-Way ANOVA of The Post-Flight Energy Drink Perception (The Energ

Post-Flight Energy Drink Perception	Users N=35 *M* (*SD*
Energy drinks have an effect on a student pilot’s ability to pilot an aircraft.	4.43 (1.9
Energy drinks are an effective and safe method to increase a student pilot’s mental and physical performance.	3.29 (1.5
Student pilots should not consume an energy drink on same day they operate an aircraft.	2.60 (1.2

*= p<.001.

Table 6.15 One-Way ANOVA of The Post-Flight Energy Drink Perception (The F

	Flight Duration			
Post-Flight Energy Drinks Perception	<1 hr *N*=50 *M* (*SD*)	1 hr *N*=8 *M* (*SD*)	1.5 hrs *N*=16 *M* (*SD*)	2 hr *N*=2 *M* (*S*
Energy drinks have an effect on a student pilot's ability to pilot an aircraft.	4.43 (1.71)	4.38 (.74)	4.06 (2.08)	5.00 (1
Energy drinks are an effective and safe method to increase a student pilot's mental and physical performance.	3.41 (1.66)	3.25 (1.17)	2.31 (1.14)	2.86 (1
Student pilots should not consume an energy drink on same day they operate an aircraft.	3.22 (1.56)	3.75 (1.91)	3.50 (1.51)	3.76 (1

6.4 Subjective Sleepiness and Alertness Results

6.4.1 KSS Score (the Treatment Groups)

Table 6.16 presents *means* and *standard deviation*s of the KSS Score at the pre-flight and post-flight test between the treatment groups. At the pre-flight test phase, participants in the Red Bull group rated their sleepiness levels on the KSS was slightly higher but was not significant. At the post-flight test phase, participants in the Red Bull group rated their sleepiness levels was also slightly higher. Overall, it can be seen that participants in the Red Bull group was less alert (or more sleepy) than participants in the water group.

Table 6.16 KSS Score

KSS	Water (*N*=55) M (*SD*)	Red Bull (*N*=55) M (*SD*)
Pre-Flight KSS	3.60 (1.61)	3.64 (1.83)
Post-Flight KSS	3.65 (1.57)	3.73 (1.68)

A 2 (treatment groups: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on KSS Score. Levene's Test of Equality of Error Variances ($p > .05$) and Box's Test of Equality of Covariance Matrices ($p > .001$) were not significant. Wilks' Lambda did not indicate any significant interaction effects ($p > .05$). The mixed model ANOVA found no evidence of a main effect for the within subjects factors – pre-flight test vs. post-flight test scores, F (1,108) = .19, p = .66, $\eta^2 = .002$. There was no evidence of a difference between the treatment groups, F (1,108) = .40, p = .84. In addition, there was no evidence of a significant interaction between the treatment groups and the KSS Score, F

(1,108) = .01, *p* = .91, which indicates that the treatment groups did not have significantly different changes from pre-flight to post-flight test scores. A Means Plot described in Figure 6.1, presents how each group rated the KSS in the pre-flight test and post-flight test, and with each line representing one group.

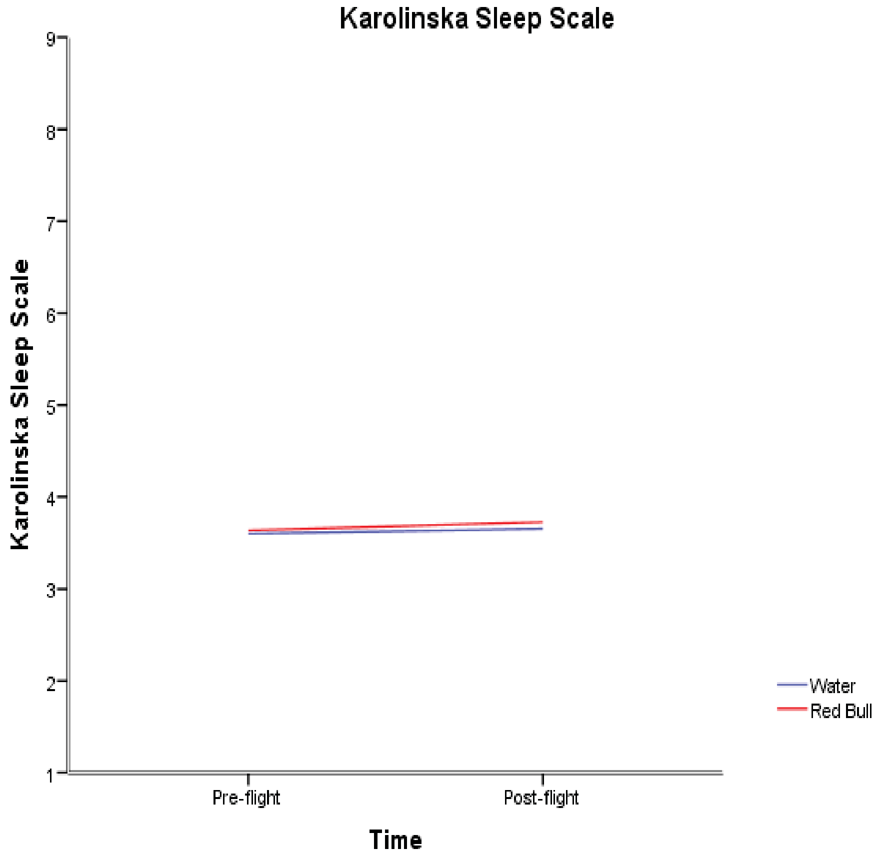

Figure 6.1 Means Plot KSS Score (The Treatment Groups)

6.4.2 KSS Score (The Flight Duration Groups)

Table 6.17 presents *means* and *standard deviations* of the KSS Score at the pre-flight and post-flight test phase between five flight duration groups. It can be seen that participants in the first three groups (<1 hour, 1 hour and 1.5 hours) had some improvements in their alertness levels and some reductions in their sleepiness. However, participants in the other two groups (2 hours and 2.5 hours) had some improvements in their sleepiness levels and some reductions in their alertness. Overall, participants became less alert in the flight duration groups of 2 hours and 2.5 hours after their flights compared with participants in the flight duration groups of <1 hour, 1 hour and 1.5 hours.

Table 6.17 KSS Score (The Flight Duration Groups)

KSS	Flight Duration <1 hr *N*=50 M (*SD*)	 1 hr *N*=8 M (*SD*)	 1.5 hrs *N*=16 M (*SD*)	 2 hrs *N*=21 M (*SD*)	 2.5hrs *N*=15 M (*SD*)
Pre-Flight KSS	4.02 (1.96)	3.50 (.93)	2.88 (1.20)	3.33 (1.56)	3.53 (1.60)
Post-Flight KSS	3.86 (1.74)	3.38 (.74)	2.81 (1.42)	3.76 (1.73)	4.13 (1.36)

A 5 (flight duration groups) × 2 (test: pre-flight vs. post-flight) mixed ANOVA was conducted to compare five groups of participants on the KSS Score. Levene's Test of Equality of Error Variances ($p > .05$) and Box's Test of Equality of Covariance Matrices ($p > .001$) were not significant. Wilks' Lambda did not indicate any significant interaction effects ($p > .05$). The mixed model ANOVA found no evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, F (1,105) = .48, $p = .49$, $\eta^2 = 1.44$. There was no evidence of a difference between groups, F (4,105) = 2.00, $p = .10$. In addition, there was no evidence of an interaction between five groups and the KSS Score, F (4,105) = .85, $p = .50$, which indicates that the groups did not have significantly different changes from pre-flight test to post-flight test scores. However, the Tukey post hoc tests indicated there was a marginally significant difference between the <1 hour and 1 hour flight duration groups (*p* =.057) on the KSS Score. However, Bonferroni correction indicated no significant difference between the <1 hour and 1 hour flight duration groups (*p* = .076) on the KSS Score. A Means Plot described in Figure 6.2, presents how each group rated the KSS in the pre-flight test and post-flight test, and with each line representing one group.

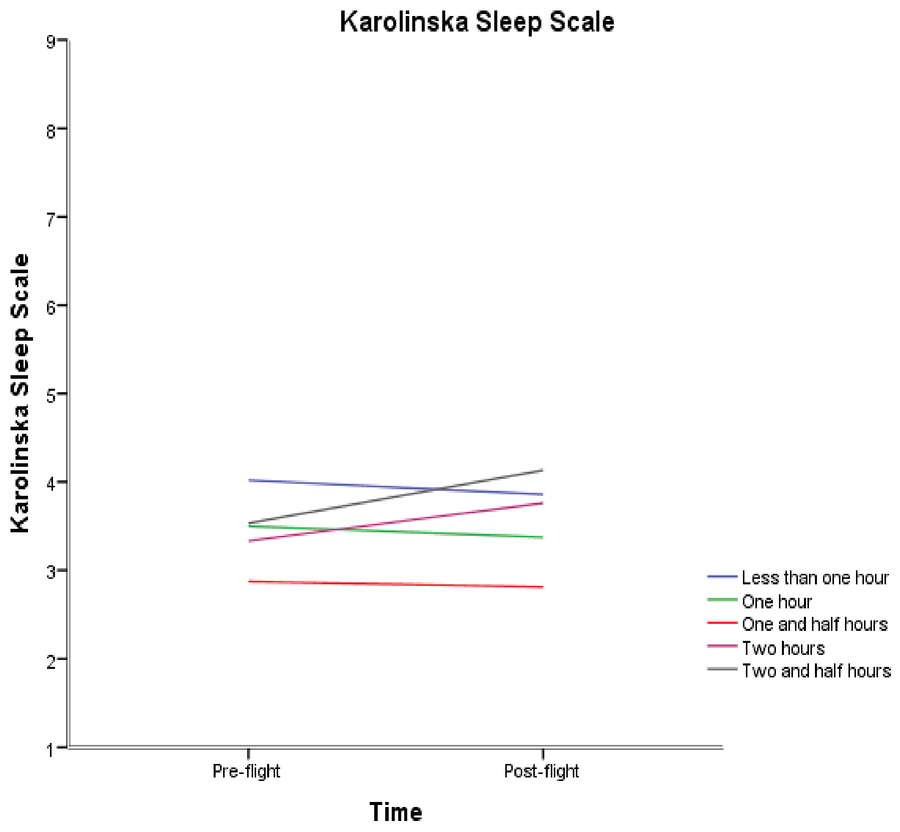

Figure 6.2 Means Plot KSS Score (The Flight Duration Groups)

6.5 Pre-Flight Items Results

Five types of aircraft, two types of cockpit displays, and five categories of flight lessons were recorded at the pre-flight phase. Table 6.18 presents the distributions of these pre-flight characteristics variables across the treatment groups. Approximately 24.5% of the participants were flying C-172s, 65.5% were using analogue cockpit display on their flights, and 47.3% were doing circuits and general handlings during their flights. A Chi-square test was conducted to analyse these pre-flight categorical data. The distributions of participants in the treatment groups did not differ significantly by aircraft types, $\chi^2(4, N = 110) = .993$, $p = .91$, cockpit displays, $\chi^2(1, N = 110) = .161$, $p = .69$ and training lessons, $\chi^2(4, N = 110) = 2.80$, $p = .59$.

Table 6.18 Pre-Flight Characteristics

Pre-flight Characteristics	All, *N*=110 *n*	Water, *N*=55 *n*	Red Bull, *N*=55 *n*	*df*	χ^2	*p*
Aircraft Types				4	.99	.91
C-172	27	13	14			
DA-20	26	13	13			
DA-40	25	11	14			
C-152	17	10	7			
PA-38	15	8	7			
Cockpit Display Types				1	.16	.69
Analogue	72	37	35			
Glass Cockpit	38	18	20			
Flight Training Lessons				4	2.80	.59
Circuits & General Handlings	52	25	27			
PPL Revisions	5	2	3			
Cross-country	26	13	13			
CPL Revisions	11	8	3			
C-Cat Revisions	16	7	9			

6.6 In-Flight Pilot Performance Results

Five flight durations were recorded (see Table 6.19), 45.5% of participants reported that their flight durations were less than one hour. A Chi-square test was conducted and distribution of the participants in the treatment groups did not differ significantly by flight duration, χ^2 (4, N = 110) = 4.93, p = .29.

Table 6.19 Flight Durations

In-Flight Characteristics	All, *N*=110 *n*	Water, *N*=55 *n*	Red Bull, *N*=55 *n*	*df*	χ^2	*p*
Flight duration				4	4.93	.29
<1 hr	50	23	27			
1 hr	8	7	1			
1.5 hrs	16	8	8			
2 hrs	21	10	11			
2.5 hrs	15	7	8			

Table 6.20 presents *means* and *standard deviations* of participants' flight performance evaluations between the water and the Red Bull treatment groups. A one-way ANOVA was conducted and the responses indicated there was a significant difference between treatment groups in terms of "*I made small mistakes or forgot things near at the end of the flight*", F (2,108) = 9.12, p = .003.

A separate one-way ANOVA was conducted to investigate flight performance evaluations by the flight duration groups. The results are presented in Table 6.21. The responses indicated there was a significant difference between the flight duration groups in terms of "*There was a high workload throughout the flight*", F (4,109) = 3.07, p = .02. In addition, the Tukey post hoc tests indicated that there was a significant difference between the <1 hour flight duration group and 1.5 hour flight duration group

(p = .015) in terms of responding to this statement. Bonferroni correction indicated the similar outcome between the same groups (p = .017).

The responses indicated there was a significant difference between the flight duration groups in terms of "*I would be able to perform at the same level of proficiency on another similar training flight to be commenced now*", F (4,109) = 2.54, p = .04. In addition, the Tukey post hoc tests indicated that there was a marginally significant difference between 1 hour and 2.5 hours flight duration groups (p = .057). However, Bonferroni correction indicated there was no significant difference between 1 hour and 2.5 hours flight duration groups (p = .076) in terms of responding to the statement.

The responses indicated that there was a significant difference between the flight duration groups, in terms of "*I would be able to perform at a higher level on another similar training flight to be commenced now*", F (4,109) = 2.75, p = .03. The Tukey post hoc tests indicated that there was a significant difference between the <1 hour and 2.5 hours flight duration groups (p = .042). There was a significant difference between 1 hour and 2.5 hours flight duration groups (p = .036). In addition, Bonferroni correction had a similar outcome, and indicated that there was a marginal significant difference between the <1 hour and 2.5 hours flight duration groups (p = .054) and there was a significant difference between 1 hour and 2.5 hours flight duration groups (p = .046) in terms of responding to the statement.

Table 6.20 One-Way ANOVA of The Post-Flight Performance Evaluation (Th

Performance Evaluation Items	All, *N*=110 *M* (*SD*)	Water, *N*=55 *M* (*SD*)	R *M*
There was a high workload throughout the flight.	4.07 (1.46)	4.07 (1.46)	4.0
I found it easy to recall important points and concepts relating to the training flight.	5.57 (1.10)	5.76 (.94)	5.3
My performance gradually decreased throughout the flight.	2.77 (1.33)	2.60 (1.27)	2.9
My performance sharply decreased near the end of the flight.	2.10 (1.20)	1.96 (1.07)	2.2
I would be able to perform at the same level of proficiency on another similar training flight to be commenced now.	5.02 (1.40)	5.11 (1.32)	4.9
I would be able to perform at a higher level on another similar training flight to be commenced now.	4.11 (1.63)	4.36 (1.66)	3.8
I became easily distracted at times near the end of the flight.	2.57 (1.28)	2.44 (1.26)	2.7
I made small mistakes or forgot things at the start of the flight.	2.86 (1.50)	2.65 (1.49)	3.0
I made small mistakes or forgot things near at the end of the flight.	2.85 (1.47)	2.44 (1.41)	3.2
My flying ability improved over the course of the flight.	4.72 (1.34)	4.83 (1.40)	4.6
I was able to maintain a focus on the requirements of the training flight throughout its duration.	5.75 (.89)	5.82 (.84)	5.

Table 6.21 One-Way ANOVA of The Post-Flight Performance Evaluation (The F

Performance Evaluation Items	Flight Duration <1 hr *N*=50 *M* (*SD*)	1 hr *N*=8 *M* (*SD*)	1.5 hrs. *N*=16 *M* (*SD*)	2 *N* *M*
There was a high workload throughout the flight.	3.64 (1.59)	3.88 (1.81)	4.94 (1.24)	4.38
I found it easy to recall important points and concepts relating to the training flight.	5.48 (1.42)	5.88 (.64)	6.13 (.62)	5.4
My performance gradually decreased throughout the flight.	2.66 (1.38)	2.63 (1.19)	2.50 (1.27)	2.90
My performance sharply decreased near the end of the flight.	2.28 (1.34)	1.88 (.64)	1.63 (1.09)	2.10
I would be able to perform at the same level of proficiency on another similar training flight to be commenced now.	5.14 (1.50)	5.75 (.89)	5.31 (1.35)	4.80
I would be able to perform at a higher level on another similar training flight to be commenced now.	4.32 (1.61)	5.00 (1.20)	4.19 (1.52)	4.00
I became easily distracted at times near the end of the flight.	2.72 (1.44)	2.25 (.71)	2.25 (1.00)	2.48
I made small mistakes or forgot things at the start of the flight.	2.98 (1.46)	2.13 (.84)	2.69 (1.58)	2.52
I made small mistakes or forgot things near at the end of the flight.	2.74 (1.35)	2.00 (.54)	2.88 (1.54)	2.81
My flying ability improved over the course of the flight.	4.80 (1.34)	5.25 (1.04)	5.00 (1.21)	4.71
I was able to maintain a focus on the requirements of the training flight throughout its duration.	5.72 (.90)	5.88 (.64)	6.19 (.75)	5.6

6.7 In-Flight Pilot Fatigue Results

The question of "*How manageable is it to remain alert during a usual flight lesson?*" was presented to all participants. Results by the treatment groups suggested that 57.3% of participants reported that it was easy to remain alert during a usual flight lesson. A Chi-square test was conducted and the response indicated that distribution of participants did not differ by the treatment groups, χ^2 (3, N = 110) = 3.13, p = .37 (see Table 6.22).

Table 6.22 Managing In-Flight Fatigue

Fatigue Management	All N=110 n	Water N=55 n	Red Bull N=55 n	df	χ^2	p
				3	3.13	.37
Very Difficult	*	*	*			
Difficult	2	1	1			
Neutral	19	13	6			
Easy	63	29	34			
Very Easy	26	12	14			

*= zero response.

The question of "*How many times have you fallen asleep in the cockpit while flying?*" was presented to all participants. A Chi-square test was conducted and indicated that the number of participants who had fallen asleep and who had not fallen asleep while flying were not significant by treatment, χ^2 (1, N = 110) = 1.89, p = .17 and 4.5% reported of falling asleep in the cockpit while flying (see Table 6.23).

Table 6.23 In-Flight Micro-Sleep

Micro-Sleep	All *N*=110 *n*	Water *N*=55 *n*	Red Bull *N*=55 *n*	*df*	χ^2	*p*
				1	1.89	.17
0	105	51	54			
1	5	4	1			

The question of "*In what way has fatigue affected your flight performance*?" was presented to all participants. The responses indicated that there was a marginal significant difference between the treatment groups in terms of "*Performance degraded"*, χ^2 (1, *N* = 110) = 3.51, *p* = .06. The responses of "*Alertness degraded*" and "*could not concentrate*" found no significant difference between the treatment groups. Table 6.24 presents the results of the effects of fatigue on pilot performance between the treatment groups.

Table 6.24 In-Flight Fatigue Effects

Fatigue Effects	All *N*=110 *n*	Water *N*=55 *n*	Red Bull *N*=55 *n*	*df*	χ^2	*p*
Could Not Concentrate				1	.00	1.00
Yes	40	20	20			
No	70	35	35			
Alertness Degraded				1	.04	.85
Yes	55	27	28			
No	55	28	27			
Performance Degraded				1	3.51	.06
Yes	77	34	43			
No	33	21	12			

The question of "*When your flight performance is affected by fatigue, which phase of flight performance is affected?*" was presents to all participants. Table 6.25 presents the results of the effects of fatigue on flight phase between the treatment groups.

Table 6.25 Flight Phase Affected by Fatigue

Flight Phase	All, *N*=110 *n*	Water *N*=55 *n*	Red Bull *N*=55 *n*	*df*	χ^2	*p*
Pre-Flight Planning				1	.15	.70
Yes	44	21	23			
No	66	34	32			
Pre-Flight/Walk-Around				1	.10	.75
Yes	11	5	6			
No	99	50	49			
Engine Start/Taxi				1	5.64	.02
Yes	17	13	4			
No	93	42	51			
Take-off				1	.37	.54
Yes	12	5	7			
No	98	50	48			
En-route				1	1.49	.22
Yes	74	34	40			
No	36	21	15			
Descent				1	.06	.81
Yes	21	10	11			
No	89	45	44			
Approach/Landing				1	.34	.56
Yes	43	20	23			
No	67	35	32			
Engine Shutdown				1	1.17	.28
Yes	16	6	10			
No	94	49	45			

Participants reported that en-route was the most fatigue affected flight phase (67.3%). Participants also reported that they were affected by fatigue in the pre-flight planning (40%) and the approach/landing phase (39.1%). Pre-flight/walk-around phrase (10%) was the least fatigue affected. In addition, the number of participants who reported fatigue in the engine start/taxi phase was significant different between the treatment groups, χ^2 (1, N = 110) = 5.64, p = .02.

In addition, "*How manageable is it to remain alert during a usual flight lesson?*" were analysed between the sleep duration groups. Table 6.26 presents the results of the managing in-flight fatigue among different sleep duration groups. No significant differences were found between the sleep duration groups in terms of managing in-flight fatigue. The responses to the question "*How many times have you fallen asleep in the cockpit while flying?*" were analysed (see Table 6.27). The number of participants who reported micro-sleep occurrence was close to the significant level between the sleep duration groups, χ^2 (9, N = 110) = 6.59, p = .09.

Table 6.26 Managing In-Flight Fatigue (The Sleep Duration Groups)

		Sleep Duration (hours)						
	All *N*=110	≤ 6 *N*=6	6.1–7.0 *N*=15	7.1–8.0 *N*=39	≥8.1 *N*=50			
Fatigue Management	*n*	*n*	*n*	*n*	*n*	*df*	χ^2	*p*
						9	5.64	.78
Very Difficult	*	*	*	*	*			
Difficult	2	*	1	1	*			
Neutral	19	1	3	8	7			
Easy	63	4	9	22	28			
Very Easy	26	1	2	8	15			

*= zero response.

Table 6.27 In Flight Micro-Sleep (The Sleep Duration Groups)

		Sleep Duration (hours)						
	All	≤ 6	6.1–7.0	7.1–8.0	≥8.1			
	N=110	*N*=6	*N*=15	*N*=39	*N*=50			
Micro-Sleep	*n*	*n*	*n*	*n*	*n*	*df*	χ^2	*p*
						9	6.59	.09
0	105	5	13	39	48			
1	5	1	2	*	2			

*= zero response

Table 6.28 presents the results of the effects of fatigue on pilots' performance between the sleep duration groups. No significant differences between the sleep duration groups were found in terms of in-flight fatigue effects.

Table 6.28 In-Flight Fatigue Effects (The Sleep Duration Groups)

		Sleep Duration (hours)						
	All	≤ 6	6.1–7.0	7.1–8.0	≥8.1			
	N=110	*N*=6	*N*=15	*N*=39	*N*=50			
Fatigue Effects	*n*	*n*	*n*	*n*	*n*	*df*	χ^2	*p*
Could Not Concentrate						3	.52	.91
Yes	40	2	5	13	20			
No	70	4	10	26	30			
Alertness Degraded						3	1.32	.72
Yes	55	3	6	22	24			
No	55	3	9	17	26			
Performance Degraded						3	.95	.81
Yes	77	4	12	26	35			
No	33	2	3	13	15			

*= zero response

Table 6.29 presents the results of the effects of pilot fatigue on different flight phase between the sleep duration groups. No significant differences between the sleep duration groups were found in terms of the effects of fatigue on the flight phase.

Table 6.29 Flight Phase Affected by Fatigue (The Sleep Duration Groups)

	Sleep Duration (hours)							
	All	≤ 6	6.1–7.0	7.1–8.0	≥8.1			
	N=110	*N*=6	*N*=15	*N*=39	*N*=50			
Flight Phase	*n*	*n*	*n*	*n*	*n*	*df*	χ^2	*p*
Pre-Flight Planning						3	1.14	.77
Yes	44	3	5	14	22			
No	66	3	10	25	28			
Pre-Flight/Walk-Around						3	3.23	.36
Yes	11	*	*	4	7			
No	99	6	15	35	43			
Engine Start/Taxi						3	5.58	.13
Yes	17	*	1	4	12			
No	93	6	14	35	38			
Take-off						3	.90	.83
Yes	12	*	2	4	6			
No	98	6	13	35	44			
En-route						3	1.17	.76
Yes	74	3	11	27	33			
No	36	3	4	12	17			
Descent						3	.42	.94
Yes	21	1	2	8	10			
No	89	5	13	31	40			
Approach/Landing						3	2.23	.53
Yes	43	2	6	12	23			
No	67	4	9	27	27			
Shutdown						3	3.89	.27
Yes	16	1	1	9	5			
No	94	5	14	30	45			

*= zero response.

6.8 Fatigue Countermeasures Results

Table 6.30 presents the results of fatigue countermeasures between the treatment groups. The results indicated that the distribution of participants between the treatment groups were significant differences by the following common countermeasures, respectively, napping, χ^2 (1, N = 110) = .71, p = .40; coffee use, χ^2 (1, N = 110) = 1.3, p = .25; soft drinks use, χ^2 (1, N = 110) = .96, p = .33; tea use, χ^2 (1, N = 110) = .38, p = .54 and nicotine use, χ^2 (1, N = 110) = .00, p = 1.00. In addition, 70.9% of the participants reported that they didn't nap to supplement sleep, 49.1% reported of consuming coffee, 39.1% reported of consuming soft drinks, 31.8% reported of consuming tea, and 12.7% reported of consuming nicotine each day.

Table 6.30 Fatigue Countermeasures

Countermeasures	All N=110 n	Water N=55 n	Red Bull N=55 n	*df*	χ^2	*p*
Napping				1	.71	.40
Yes	32	14	18			
No	78	41	37			
Coffee				1	1.3	.25
Yes	54	24	30			
No	56	31	25			
Soft Drinks				1	.96	.33
Yes	43	19	24			
No	67	36	31			
Tea				1	.38	.54
Yes	35	19	16			
No	75	36	39			
Cigarettes				1	.00	1.00
Yes	14	7	7			
No	96	48	48			

Table 6.31 presents the results of the number of fatigue countermeasures used each day between the treatment groups. The number of fatigue countermeasures used had a no significant difference between the treatment groups, respectively, coffee use, χ^2 (3, N = 110) = 5.77, p = .12; soft drinks use, χ^2 (3, N = 110) = 1.08, p = .78; tea use, χ^2 (3, N = 110) =.85, p = .84 and nicotine use, χ^2 (3, N = 110) =.53, p = .91.

Table 6.31 Fatigue Countermeasures Used Per Day

Quantities	All *N*=110 *n*	Water *N*=55 *n*	Red Bull *N*=55 *n*	*df*	χ^2	*p*
Coffee				3	5.77	.12
1	25	14	11			
2	17	4	13			
≥3	12	6	6			
Soft Drinks				3	1.08	.78
1	26	11	15			
2	11	5	6			
≥3	6	3	3			
Tea				3	.85	.84
1	16	9	7			
2	7	3	4			
≥3	12	7	5			
Cigarettes				3	.53	.91
1	3	1	2			
2–5	5	3	2			
≥6	6	3	3			

Table 6.32 presents the results of fatigue countermeasures between the sleep duration groups. A Chi-square test indicated that participants used napping as a fatigue countermeasure were significantly different between the sleep duration groups, χ^2 (3, N = 110) = 10.45, p = .015. A one-way ANOVA confirmed the similar outcome, F (3,

106) = 3.71, *p* = .014. In addition, the Tukey post hoc tests indicated that there was a significant difference between 6.1–7.0 hrs and ≥8.1 hrs sleep duration groups (*p* = .014) in terms of napping; and Bonferroni correction indicated the similar outcome (*p* = .015) between the same groups.

Table 6.32 Fatigue Countermeasures (The Sleep Duration Groups)

Fatigue Countermeasures	All *N*=110 *n*	Sleep Duration (hours) ≤ 6 *N*=6 *n*	6.1–7.0 *N*=15 *n*	7.1–8.0 *N*=39 *n*	≥8.1 *N*=50 *n*	*df*	χ^2	*p*
Napping						3	10.45	.015
Yes	32	3	9	10	10			
No	78	3	6	29	40			
Coffee						3	3.26	.35
Yes	54	4	5	22	23			
No	56	2	10	17	27			
Soft Drinks						3	2.65	.45
Yes	43	1	5	14	23			
No	67	5	10	25	27			
Tea						3	1.84	.61
Yes	35	2	7	11	15			
No	75	4	8	28	35			
Cigarettes						3	6.10	.11
Yes	14	1	2	1	10			
No	96	5	13	38	40			

Table 6.33 presents the results of the number of fatigue countermeasures used between the sleep duration groups. A Chi-square test indicated there were no significant differences in sleep durations and the number of fatigue countermeasures used, respectively, coffee, χ^2 (9, *N* = 110) = 4.64, *p* = .87; soft drinks, χ^2 (9, *N* = 110) = 9.97, *p* = .35; tea, χ^2 (9, *N* = 110) = 5.41, *p* = .80 and cigarettes, χ^2 (9, *N* = 110) = 14.18, *p* = .12.

Table 6.33 Fatigue Countermeasures Used Per Day (The Sleep Duration Groups)

Quantities	All *N*=110 *n*	Sleep Duration (hours) ≤ 6 *N*=6 *n*	 6.1–7.0 *N*=15 *n*	 7.1–8.0 *N*=39 *n*	 ≥8.1 *N*=50 *n*	*df*	χ^2	*p*
Coffee						9	4.64	.87
1	25	2	2	12	9			
2	17	1	2	6	8			
≥3	12	1	1	4	6			
Soft Drinks						9	9.97	.35
1	26	*	2	9	15			
2	11	*	3	2	6			
≥3	6	1	*	3	2			
Tea						9	5.41	.80
1	16	*	4	4	8			
2	7	1	1	3	2			
≥3	12	1	2	4	5			
Cigarettes						9	14.18	.12
1	3	1	*	*	2			
2–5	5	*	*	1	4			
≥6	6	*	2	*	4			

*= zero response.

6.9 Subjective Pilot Fatigue Results

6.9.1 Pre-Flight Test and Post-Flight Test Items

Table 6.34 presents *means* and *standard deviations* of items in the pre-flight test and post-flight test between the treatment groups.

Table 6.34 Means and Standard Deviations of Pre-Flight and Post-Flight Items

Question	Items	Water (*N*=55) *M* (*SD*)	Red Bull (*N*=55) *M* (*SD*)
Pre-Flight			
PreQ1	Mentally, I am well prepared to undergo the flight.	6.24 (.96)	6.16 (.94)
PreQ2	I feel energetic.	5.18 (1.17)	4.78 (1.24)
PreQ3	I feel more forgetful than normal.	2.20 (1.21)	2.31 (1.23)
PreQ4	I can concentrate very well.	5.58 (1.07)	5.56 (1.05)
PreQ5	I have an overall feeling of tiredness.	2.87 (1.48)	2.89 (1.51)
PreQ6	I feel mentally exhausted.	1.91 (1.24)	1.95 (1.15)
Post-Flight			
PostQ1	I am pleased with the outcome of the flight.	5.87 (.94)	5.89 (1.07)
PostQ2	I was well prepared to undergo the flight.	6.04 (.92)	5.95 (.97)
PostQ3	I find it difficult to concentrate.	1.96 (.82)	2.49 (1.37)
PostQ4	I can think clearly.	5.91 (1.08)	5.87 (.88)
PostQ5	I feel relaxed.	5.33 (1.23)	5.04 (1.37)
PostQ6	I feel worn out.	3.07 (1.27)	3.20 (1.46)

6.9.2 Positive Items

Positive items are analysed separately, according to previous studies by Chalder et al. (1993) and Michielsen et al. (2003). Combining the scores of the individual symptoms (e.g., Overall Well-Being = Positive Physical Items + Positive Mental Items) and the individual items (e.g., Mental Items = PreQ1 + PreQ4) were used. These are common methods in the calculation of scores for validated psychometric scales (Smit & Rogers, 2002). Six positive items were subjected to mixed model ANOVA, which consisted of two physical and four mental items (see Table 6.35).

Table 6.35 Positive Mental and Physical Items

	Question	Positive Items	Symptoms
Pre-Flight			
	PreQ1	Mentally, I am well prepared to undergo the flight.	Mental
	PreQ2	I feel energetic.	Physical
	PreQ4	I can concentrate very well.	Mental
Post-Flight			
	PostQ1	I am pleased with the outcome of the flight.	Mental
	PostQ4	I can think clearly.	Mental
	PostQ5	I feel relaxed.	Physical

Table 6.36 presents *means*, *standard deviations* and *Cronbach's alpha* coefficients of positive individual items and combined items in the pre-flight test and post-flight test.

Table 6.36 Means, Standard Deviations, and Cronbach's Alpha (Positive Items)

Scale	*M*	*SD*	*α*
Pre-Flight Positive Physical (PreQ2)	4.98	1.22	*
Post-Flight Positive Physical (PostQ5)	5.18	1.31	*
Pre-Flight Positive Mental (PreQ1 + PreQ4)	11.77	1.86	.84
Post-Flight Positive Mental (PostQ1 + PostQ4)	11.77	1.65	.56
Pre-Flight Well-Being (PreQ1 + PreQ4 + PreQ2)	16.75	2.81	.84
Post-Flight Well-Being (PostQ1 + PostQ4 + PostQ5)	16.95	2.52	.63

*= *α* was not conducted due to one item within each scale.

6.9.2.1 Positive Physical Score

Table 6.37 presents *mean*s and *standard deviations* of Positive Physical Score in the pre-flight test and post-flight test between the treatment groups.

Table 6.37 Positive Physical Score

	Water (*N* = 55) *M* (*SD*)	Red Bull (*N* = 55) *M* (*SD*)
Pre-Flight Positive Physical Score	5.18 (1.17)	4.78 (1.24)
Post-Flight Positive Physical Score	5.33 (1.23)	5.04 (1.37)
Difference Score	.15 (.06)	.07 (.13)

A 2 (treatment groups: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on Positive Physical Score. The ANOVA found no evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, *F* (1,108) = 1.43, *p* = .23, η^2 = .013. There was a difference between groups, *F* (1,108) = 4.03, *p* = .047. In addition, there was no evidence of a significant interaction between groups and Positive Physical Score, *F* (1,108) = .11, *p* = .75. A Means Plot described in Figure 6.3, presents how each group rated the positive physical items (e.g., *feeling energetic* or *feeling relaxed*) in the pre-flight test and post-flight test, and with each line representing one group.

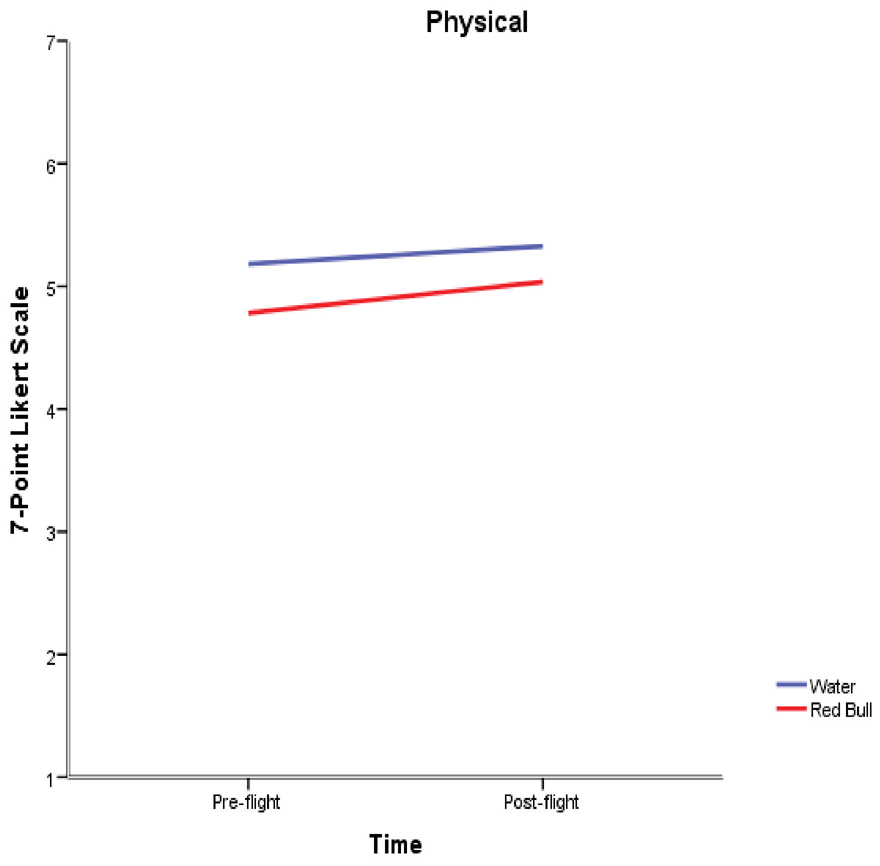

Figure 6.3 Means Plot Positive Physical Score

6.9.2.2 Positive Mental Score

Table 6.38 presents *means* and *standard deviations* of Positive Mental Score in the pre-flight test and post-flight test between the treatment groups.

Table 6.38 Positive Mental Score

	Water (*N* = 55) *M* (*SD*)	Red Bull (*N* = 55) *M* (*SD*)
Pre-Flight Positive Mental Score	5.91 (.96)	5.86 (.91)
Post-Flight Positive Mental Score	5.89 (.85)	5.88 (.81)
Difference Score	-.02 (-.11)	-.08 (-.10)

A 2 (treatment groups: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on Positive Mental Score. The ANOVA found no evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, *F* (1,108) = .00, *p* = 1.00, η^2 = .000. There was no evidence of a difference between groups, *F* (1,108) = .04, *p* = .85. In addition, there was no evidence of a significant interaction between groups and Positive Mental Score, *F* (1,108) = .04, *p* = .84. A Means Plot described in Figure 6.4, presents how each group rated the positive mental items (e.g., *mentally prepared*, *able to concentrate*, *pleased with the flight* or *able to think clearly*) in the pre-flight test and post-flight test, and with one line representing each group.

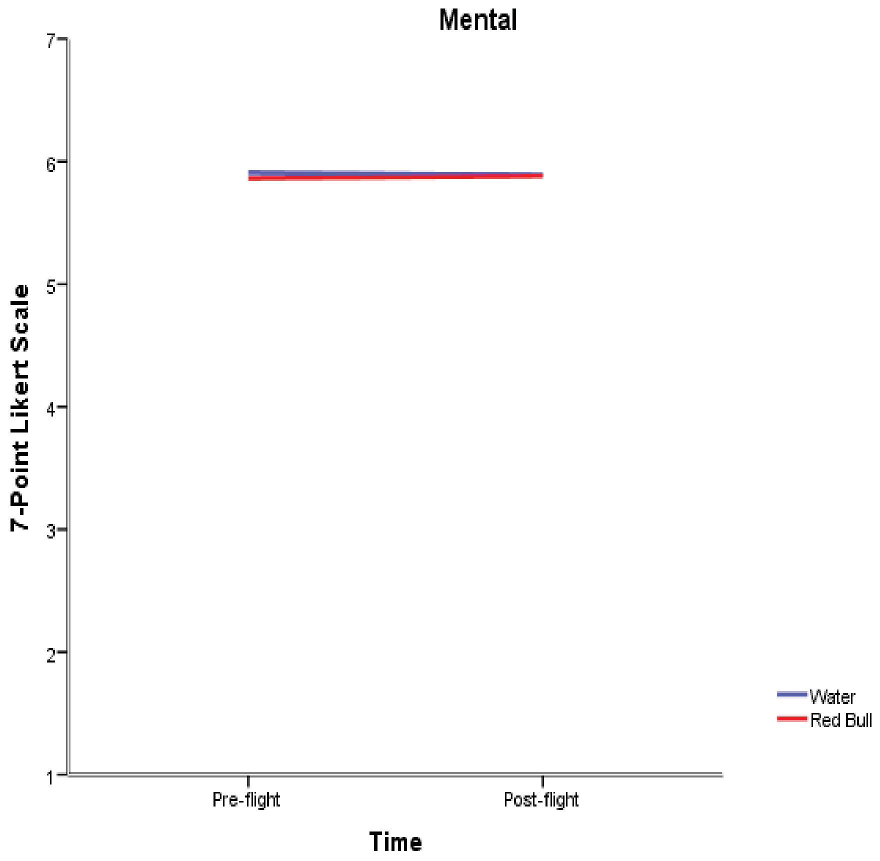

Figure 6.4 Means Plot Positive Mental Score

6.9.2.3 Cognition Score

Table 6.39 presents *means* and *standard deviations* of Cognition Score in the pre-flight test and post-flight test between the treatment groups.

Table 6.39 Cognition Score

	Water (*N* = 55) *M* (*SD*)	Red Bull (*N* = 55) *M* (*SD*)
Pre-Flight Positive Cognition Score	5.58 (1.07)	5.56 (1.05)
Post-Flight Positive Cognition Score	5.91 (1.08)	5.87 (.88)
Difference Score	.33 (-.01)	.31 (-.17)

A 2 (treatment groups: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on Cognition Score. The ANOVA found evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, F (1,108) = 9.41, p = .003, η^2 = .080. There was no evidence of a difference between groups, F (1,108) = .03, p = .87. In addition, there was no evidence of a significant interaction between groups and mean Cognition Score, F (1,108) = .01, p = .93. A Means Plot described in Figure 6.5, presents how each group rated the cognition items in the pre-flight test and post-flight test, and with one line representing each group.

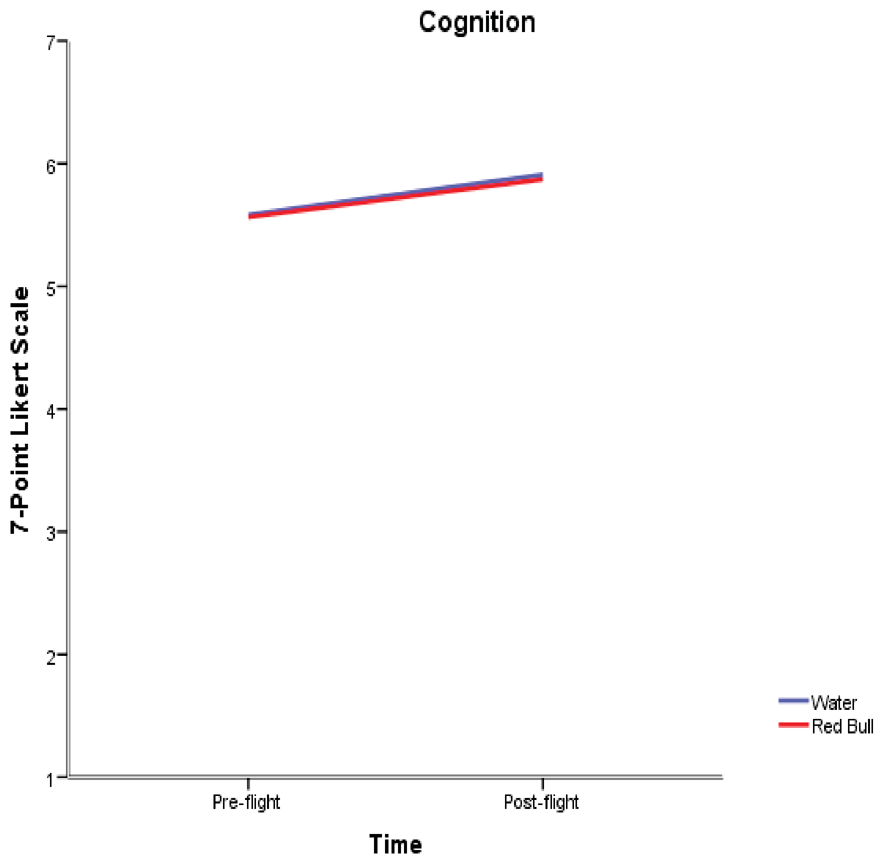

Figure 6.5 Mean Plot Cognition Score

6.9.2.4 Overall Positive Mental Score

Table 6.40 presents *mean*s and *standard deviations* of Overall Positive Mental Score in the pre-flight test and post-flight test between the treatment groups.

Table 6.40 Overall Positive Mental Score

	Water (*N* = 55) *M* (*SD*)	Red Bull (*N* = 55) *M* (*SD*)
Pre-Flight Overall Positive Mental Score	11.82 (1.93)	11.78 (1.71)
Post-Flight Overall Positive Mental Score	11.73 (1.81)	11.76 (1.61)
Difference Score	-.09 (-.12)	-.08 (-.10)

A 2 (treatment groups: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on Overall Positive Mental Score. The ANOVA found no evidence of a main effect for the within subjects factors – pre-flight test vs. post-flight test scores, *F* (1,108) = .00, *p* = 1.00, η^2 = .000. There was no evidence of a difference between groups, *F* (1,108) = .04, *p* = .85. In addition, there was no evidence of a significant interaction between groups and Total Positive Mental Score, *F* (1,108) = .04, *p* = .84. A Means Plot described in Figure 6.6, presents how each group rated the overall positive mental items in the pre-flight test and post-flight test, and with one line representing each group.

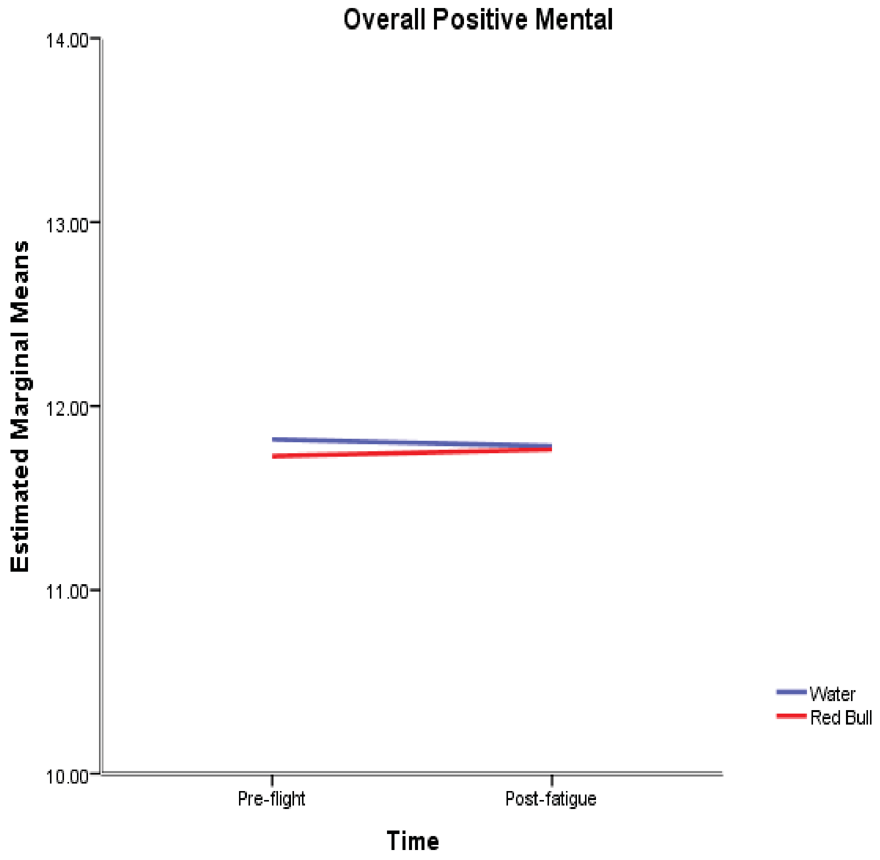

Figure 6.6 Means Plot Overall Positive Mental Score

6.9.2.5 Overall Well-Being Score

Table 6.41 presents *mean*s and *standard deviations* of Overall Well-Being Score in the pre-flight test and post-flight test between the treatment groups.

Table 6.41 Overall Well-Being Score

	Water (*N* = 55) *M* (*SD*)	Red Bull (*N* = 55) *M* (*SD*)
Pre-Flight Well-Being Score	17.00 (2.86)	16.51 (2.76)
Post-Flight Well-Being Score	17.11 (2.47)	16.80 (2.58)
Difference Score	.11 (-.39)	.29 (-.18)

A 2 (treatment groups: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was performed to compare two groups of participants on Overall Well-Being Score. The ANOVA found no evidence of a main effect for the within subjects factors – pre-flight test vs. post-flight test scores, F (1,108) = .46, p = .50, η^2 = .004. There was no evidence of a difference between groups, F (1,108) = .93, p = .34. In addition, there was no evidence of a significant interaction between groups and Overall Well-Being Score, F (1,108) = .10, p = .76. A Means Plot described in Figure 6.7, presents how each group rate the overall well-being items in the pre-flight test and post-flight test, and with one line representing each group.

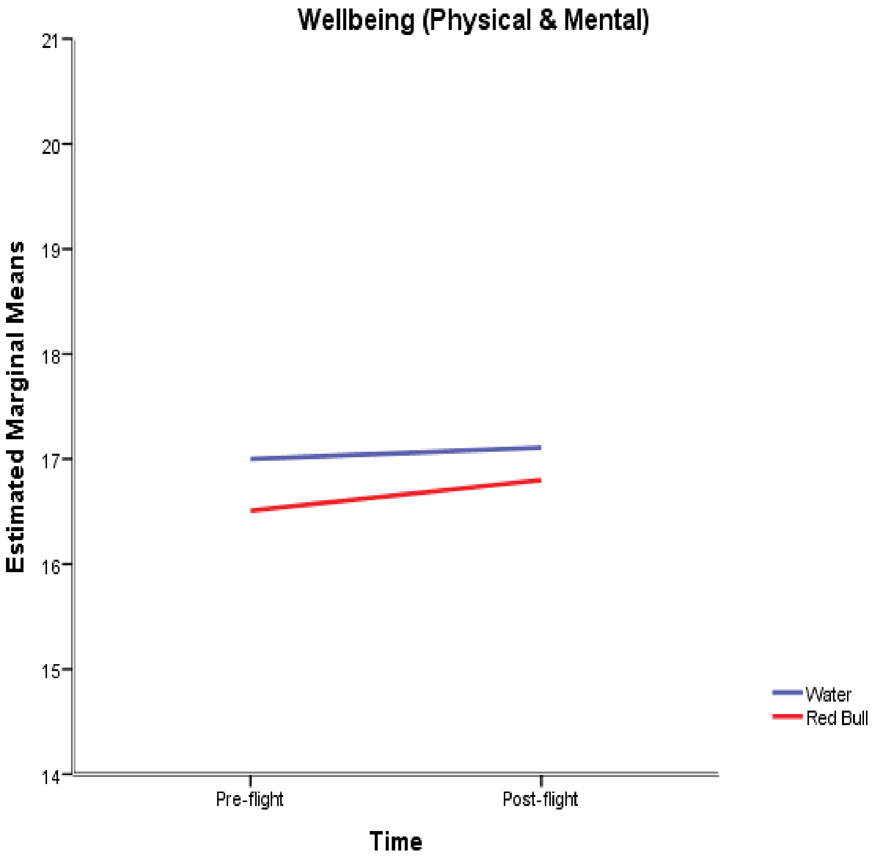

Figure 6.7 Means Plot Overall Well-Being Score

6.9.3 Negative Items

Negative items are analysed separately, according to previous studies by Chalder et al. (1993) and Michielsen et al. (2003). Four negative items were subjected to mixed model ANOVA, which consisted of two physical and two mental items (see Table 6.42).

Table 6.42 Negative Mental and Physical Items

	Question	Negative Items	Symptoms
Pre-Flight			
	PreQ5	I have an overall feeling of tiredness.	Physical
	PreQ6	I feel mentally exhausted.	Mental
Post-Flight			
	PostQ3	I find it difficult to concentrate.	Mental
	PostQ6	I feel worn out.	Physical

Table 6.43 presents *means*, *standard deviations* and *Cronbach's alpha* coefficients of negative individual items and combined items in the pre-flight test and post-flight test.

Table 6.43 Means, Standard Deviations, Cronbach's Alpha (Negative Items)

(Sub)scale	*M*	*SD*	α
Pre-Flight Negative Physical (PreQ5)	2.88	1.49	*
Post-Flight Negative Physical (PostQ6)	3.14	1.37	*
Pre-Flight Negative Mental (PreQ6)	1.93	1.19	*
Post-Flight Negative Mental (PostQ3)	2.23	1.16	*
Pre-Flight Overall Fatigue (PreQ5+PreQ6)	4.81	2.35	.69
Post-Flight Overall Fatigue (PostQ3+PostQ6)	5.36	1.97	.36

*= α was not conducted due to one item within each scale.

6.9.3.1 Negative Physical Score

Table 6.44 presents *means* and *standard deviations* of Negative Physical Score between the treatment groups.

Table 6.44 Negative Physical Score

	Water (*N* = 55) *M* (*SD*)	Red Bull (*N* = 55) *M* (*SD*)
Pre-Flight Negative Physical Score	2.87 (1.48)	2.89 (1.51)
Post-Flight Negative Physical Score	3.07 (1.27)	3.20 (1.46)
Difference Score	.20 (-.21)	.31 (-.05)

A 2 (treatment groups: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on Negative Physical Score. The ANOVA found no evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, F (1,108) = 2.16, $p = .15$, $\eta^2 = .020$. There was no evidence of a difference between groups, F (1,108) = .12, $p = .73$. In addition, there was no evidence of a significant interaction between groups and Negative Physical Score, F (1,108) = .10, $p = .75$. A Means Plot described in Figure 6.8, presents how each group rated on negative physical items in the pre-flight test and post-flight test, with one line representing each group.

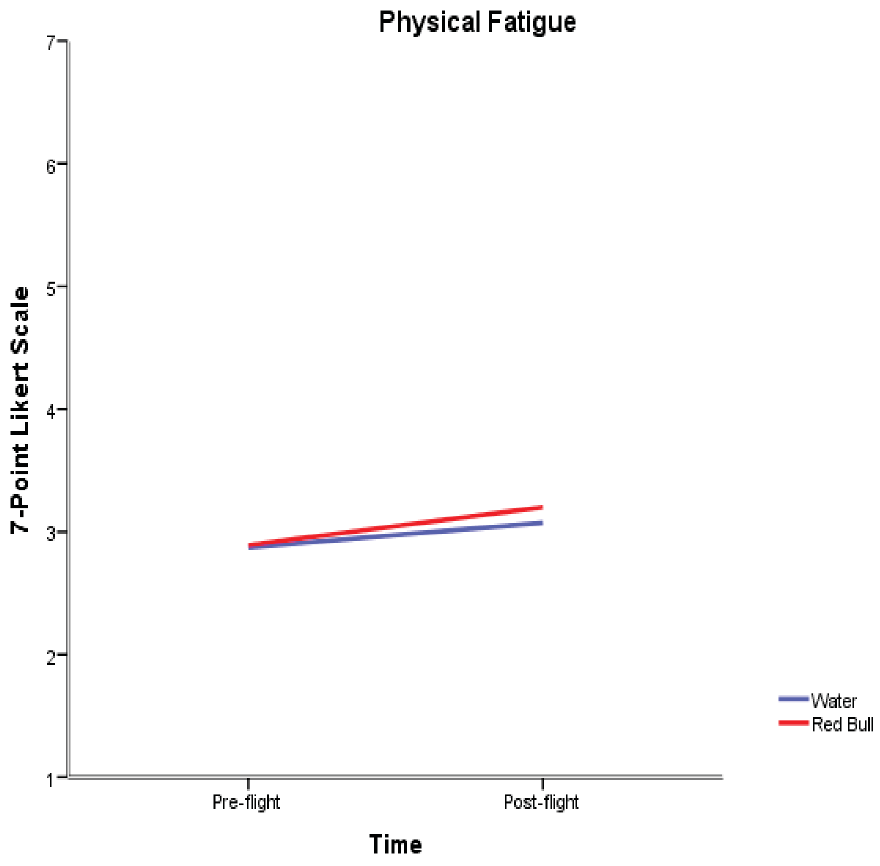

Figure 6.8 Means Plot Negative Physical Score

6.9.3.2 Negative Mental Score

Table 6.45 presents *means* and *standard deviations* of Negative Mental Score in the pre-flight test and post-flight test between the treatment groups.

Table 6.45 Negative Mental Score

	Water (*N* = 55) *M* (*SD*)	Red Bull (*N* = 55) *M* (*SD*)
Pre-Flight Negative Mental Score	1.91 (1.24)	1.95 (1.15)
Post-Flight Negative Mental Score	1.96 (.82)	2.49 (1.37)
Difference Score	.05 (-.42)	.54 (-.22)

A 2 (treatment groups: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on Negative Mental Score. The ANOVA found no evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, F (1,108) = 5.50, p = .021, η^2 = 4.95. There was no evidence of a difference between groups, F (1,108) = 2.43, p = .12. However, there was no evidence of a significant interaction between groups and Negative Mental Score time, F (1,108) = 3.68, p = .058, η^2= 3.31. A means plot described in Figure 6.8, presents how each group rated the negative mental items (e.g., *mentally exhausted* or *difficult to concentrate*) in the pre-flight test and post-flight test, and with one line representing each group.

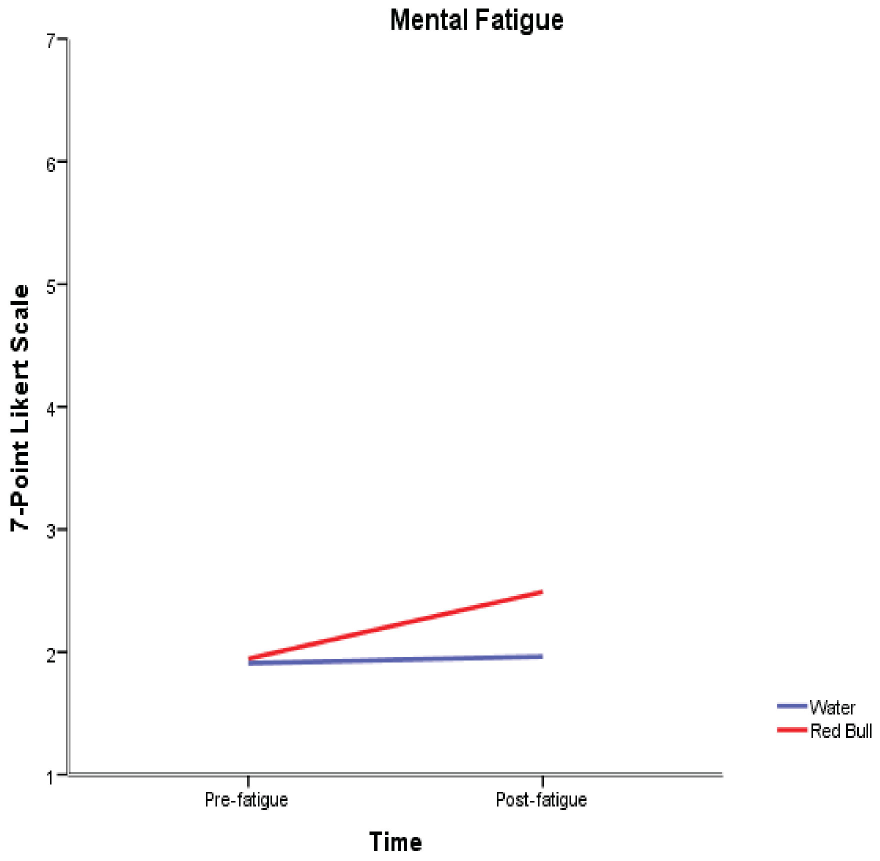

Figure 6.9 Means Plot Negative Mental Score

6.9.3.3 Overall Fatigue Score (PreQ5 + PreQ6 vs. PostQ3 + PostQ6)

Table 6.46 presents *means* and *standard deviations* of Overall Fatigue Score in the pre-flight test and post-flight test between the treatment groups.

Table 6.46 Overall Fatigue Score

	Water (*N* = 55) *M* (*SD*)	Red Bull (*N* = 55) *M* (*SD*)
Pre-Flight Overall Fatigue Score	4.87 (2.35)	4.84 (2.37)
Post-Flight Overall Fatigue Score	5.04 (1.68)	5.69 (2.19)
Difference Score	.17 (-.67)	.85 (-.18)

A 2 (treatment groups: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on Overall Fatigue Score. The ANOVA found evidence of a significant main effect for the within subjects factors – pre-flight vs. post-flight test scores, F (1,108) = 4.92, p =.029, η^2= 16.91. There is no evidence of a difference between groups, F (1,108) = 1.17, p = .28. In addition, there was no evidence of a significant interaction between groups and Overall Fatigue Score, F (1,108) = 1.44, p = .23. A Means Plot described in Figure 6.10, presents how each group rated the overall fatigue items in the pre-flight test and post-flight test, and with one line representing each group.

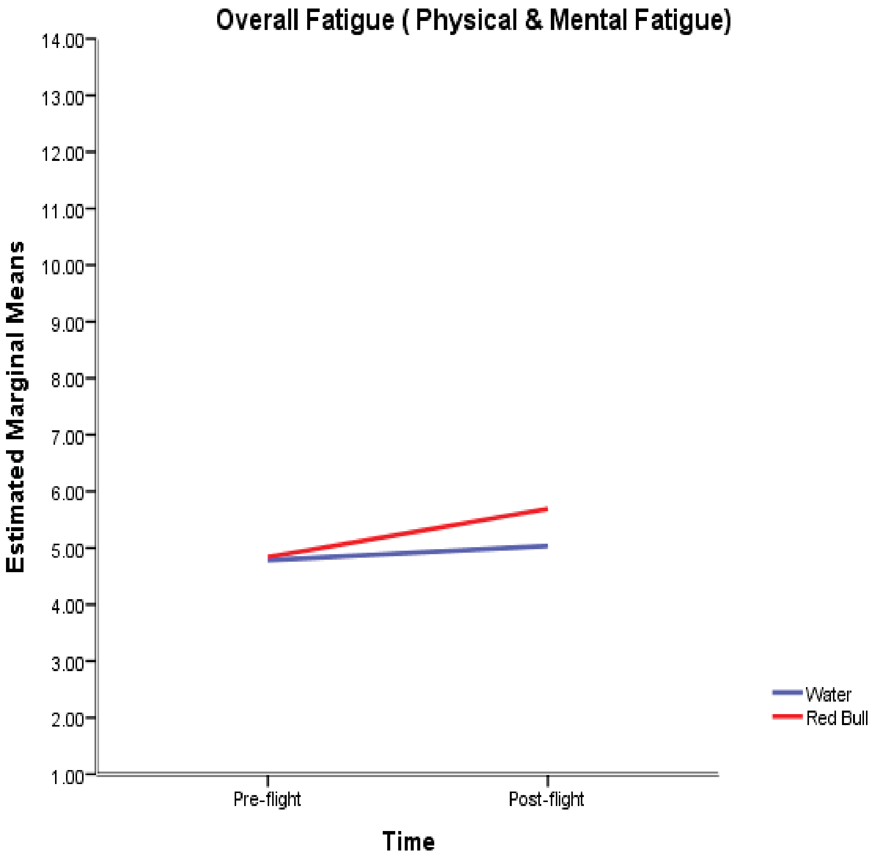

Figure 6.10 Means Plot Overall Fatigue Score

6.10 Objective Pilot Cognitive Performance Results

In total, there were nine interval delays for pre-flight PPVT test and nine interval delays for post-flight PPVT test. Table 6.47 presents *means* and *standard deviations* of response time (RTs) at each delay, too fast, lapse, correct and sleep attack. Nine separate mixed model ANOVA tests were conducted to reveal any evidence of significance on RTs at each delay and other PPVT variables between the treatment groups.

Table 6.47 Mixed Model ANOVA PPVT Score

Pre-Flight PPVT	Water (*N*=55) *M* (*SD*)	Red Bull (*N*=55) *M* (*SD*)	Post-Flight PPVT	Water (*N*=55) *M* (*SD*)	R (*M*
1000ms	514.94 (606.53)	435.62 (107.09)	1000ms	467.73 (200.94)	442.92
2000ms	388.32 (83.41)	381.52 (72.58)	2000ms	391.41 (80.15)	391.91
3000ms	365.68 (60.95)	363.74 (57.72)	3000ms	377.98 (83.23)	372.22
4000ms	374.32 (141.05)	347.73 (54.69)	4000ms	370.55 (132.06)	350.42
5000ms	355.97 (72.40)	351.11 (58.66)	5000ms	353.68 (78.62)	353.18
6000ms	349.44 (69.10)	343.30 (62.04)	6000ms	351.20 (78.10)	348.20
7000ms	342.95 (58.49)	335.81 (51.53)	7000ms	352.16 (74.22)	335.65
8000ms	348.25 (68.98)	333.25 (47.07)	8000ms	358.47 (89.11)	351.02
9000ms	348.72 (83.42)	342.70 (60.29)	9000ms	359.54 (94.79)	336.01
Mean RT	376.51 (98.49)	359.42 (54.93)	Mean RT	375.86 (83.61)	364.61
Lapse	9.49 (13.42)	7.44 (10.71)	Lapse	10.76 (13.73)	8.35
Too Fast	2.36 (3.55)	2.09 (2.78)	Too Fast	4.09 (7.79)	3.49
Correct	109.13 (13.54)	111.45 (11.94)	Correct	105.96 (15.27)	109.16
Sleep Attacks	.02 (.135)	.00 (.00)	Sleep Attacks	.00 (.00)	.00

*= p <.001;

6.10.1 RT Score at 1000ms Delay

A 2 (treatment groups: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on Response Time (RT) Score at 1000ms delay. The ANOVA found no evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, *F* (1,108) = .23, *p* = .63, η^2 = .002. There was no evidence of a difference between groups, *F* (1,108) = 1.16, *p* = .29. In addition, there was no evidence of a significant interaction between groups and RT Score at 1000ms delay, *F* (1,108) = .44 *p* = .51. A Means Plot described in Figure 6.11, presents how each group performed in the pre-flight test and post-flight test, and with one line representing each group. Participants in the Red Bull group had lower RT scores at 1000ms delay on both tests than participants in the water group.

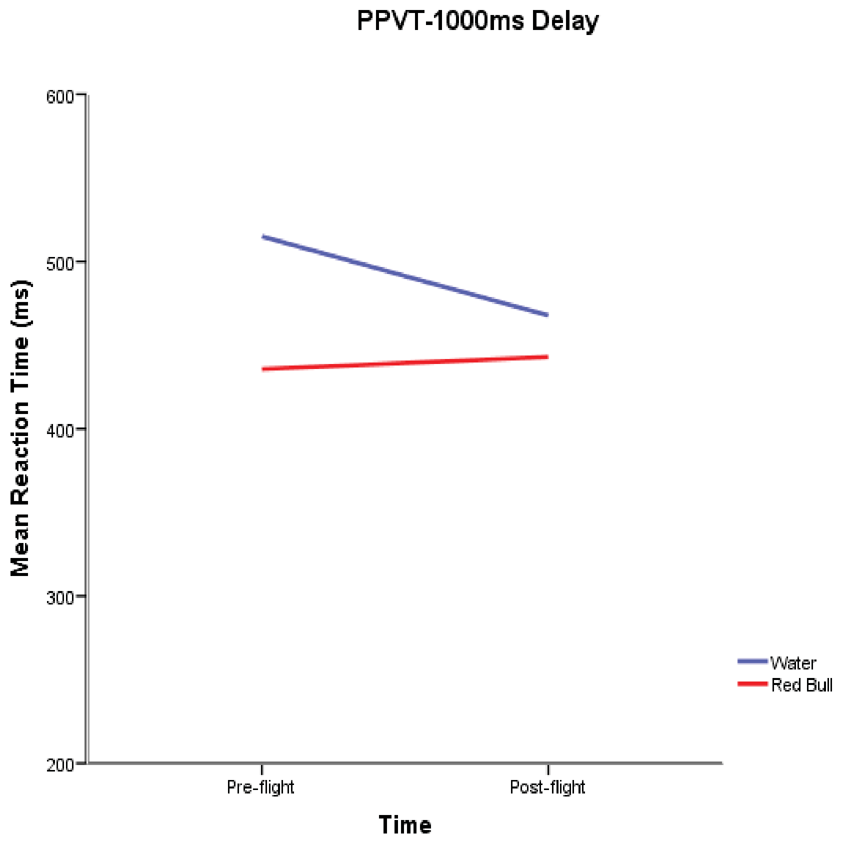

Figure 6.11 Means Plot RT Score at 1000ms Delay

6.10.2 RT Score at 2000ms Delay

A 2 (treatment groups: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on RT Score at 2000ms delay. The ANOVA found no evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, *F* (1,108) = 1.34, *p* = .25, $\eta^2 = .012$. There was no evidence of a difference between groups, *F* (1,108) = .04, *p* = .84. In addition, there was no evidence of a significant interaction between groups and RT Score at 2000ms delay, *F* (1,108) = .40 *p* = .25. A Means Plot described in Figure 6.12, presents how each group performed in the pre-flight test and post-flight test, and with one line representing each group. It can be seen that two groups of participants performed in similar fashion at 2000ms delay in the post-flight test.

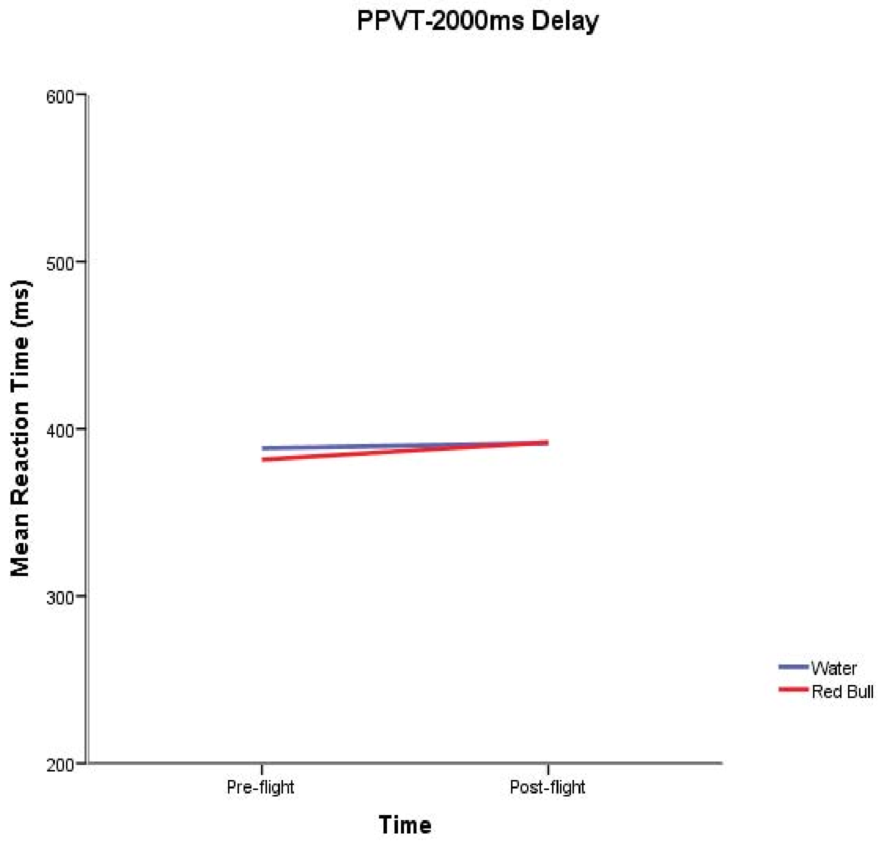

Figure 6.12 Means Plot RT Score at 2000ms Delay

6.10.3 RT Score at 3000ms Delay

A 2 (treatment groups: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on RT Score at 3000ms delay. The ANOVA found no evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, F (1,108) = 2.70, p = .10, η^2 = .024. There was no evidence of a difference between groups, F (1,108) =.09, p = .76. In addition, there was no evidence of a significant interaction between groups and RT Score at 3000ms delay, F (1,108) = .09, p = .76. A Means Plot described in Figure 6.13, presents how each group performed in the pre-flight test and post-flight test, and with one line representing each group. It can be seen that two groups of participants performed in similar fashion at 3000ms delay in the pre-flight test.

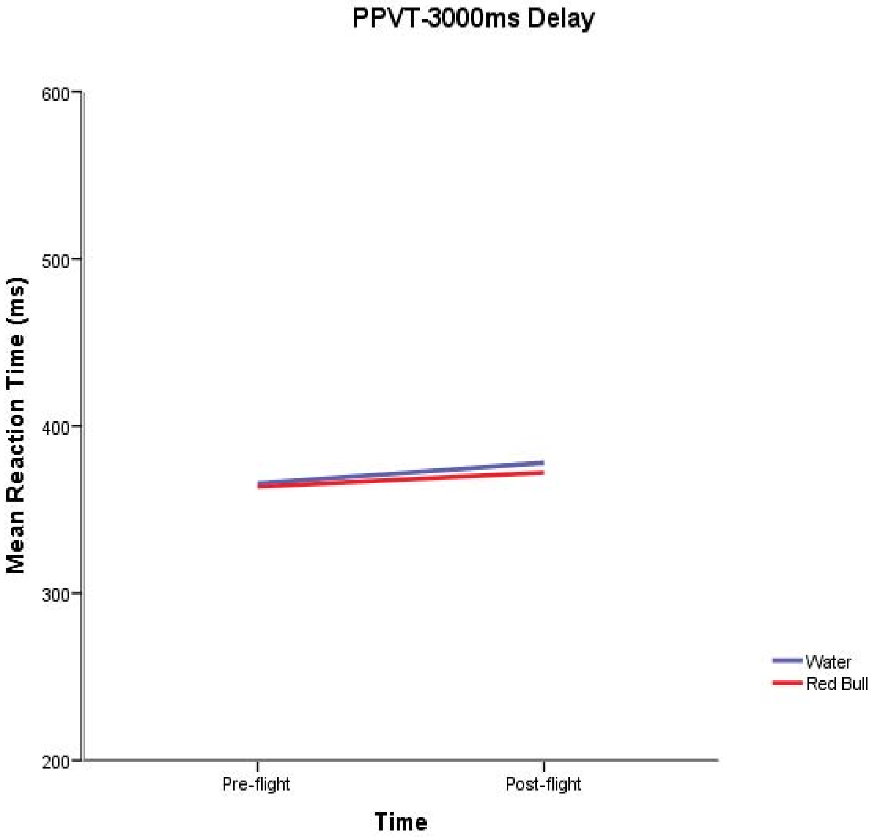

Figure 6.13 Means Plot RT Score at 3000ms Delay

6.10.4 RT Score at 4000ms Delay

A 2 (treatment groups: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on RT Score at 4000ms delay. The ANOVA found no evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, *F* (1,108) = .004, *p* = .95, η^2 = .024. There was no evidence of a difference between groups, *F* (1,108) = 1.65, *p* = .20. In addition, there was no evidence of a significant interaction between groups and RT Score at 4000ms delay, *F* (1,108) = .14, *p* = .71. A Means Plot described in Figure 6.14, presents how each group performed in the pre-flight test and post-flight test, and with one line representing each group. It can be seen that participants in the Red Bull group had lower scores at 4000ms delay than participants the water group on both tests.

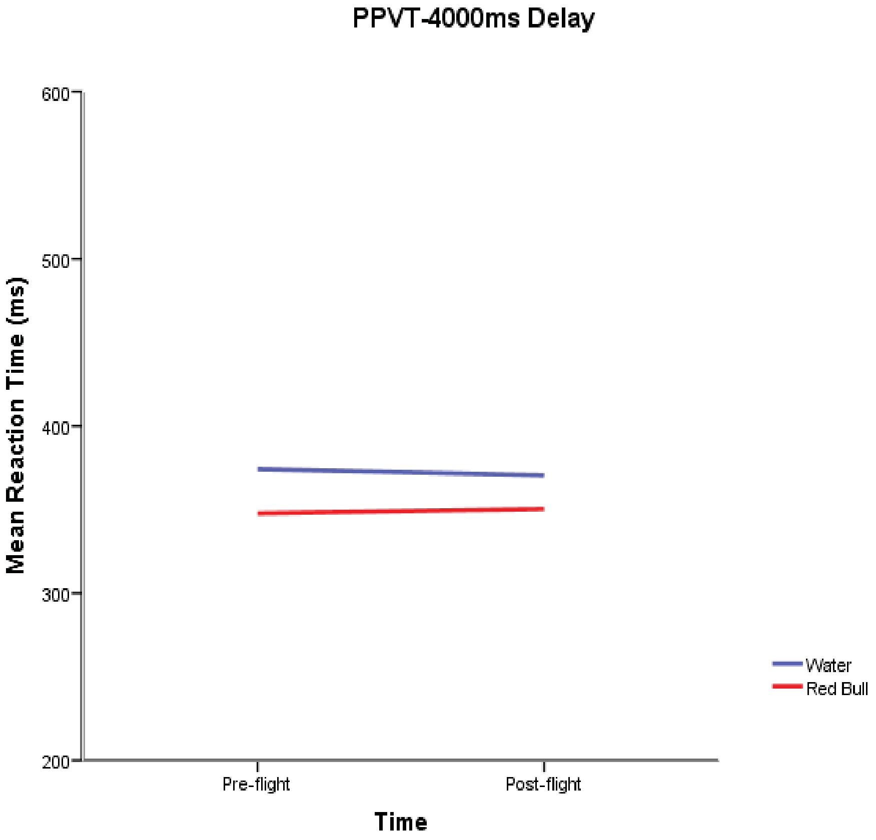

Figure 6.14 Means Plot RT Score at 4000ms Delay

6.10.5 RT Score at 5000ms Delay

A 2 (treatment groups: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on RT Score at 5000ms delay. The ANOVA found no evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, *F* (1,108) = .000, *p* = .98, $\eta^2 = .000$. There was no evidence of a difference between groups, *F* (1,108) = .05, *p* = .83. In addition, there was no evidence of a significant interaction between groups and RT Score at 5000ms delay, *F* (1,108) = .15, *p* = .70. A Means Plot described in Figure 6.15, presents how each group performed in the pre-flight test and post-flight test, and with one line representing each group. It can be seen that two groups of participants performed in similar fashion at 5000ms delay on both tests.

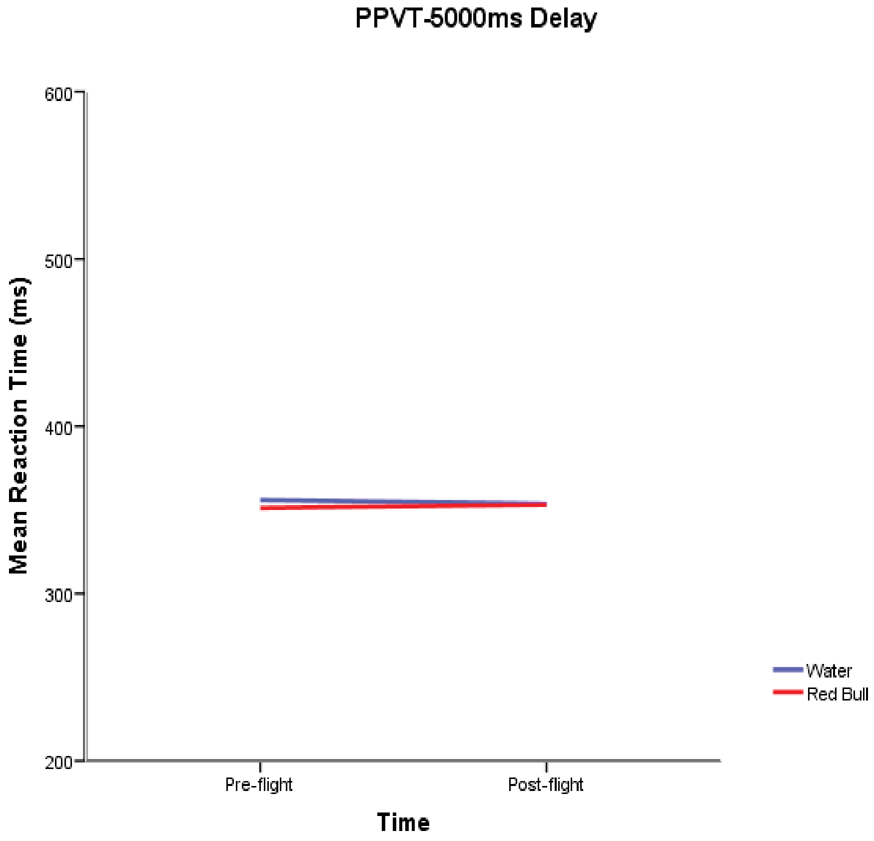

Figure 6.15 Means Plot RT Score at 5000ms Delay

6.10.6 RT Score at 6000ms Delay

A 2 (treatment groups: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on RT Score at 6000ms delay. The ANOVA found no evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, *F* (1,108) = .17, *p* = .68, $\eta^2 = .002$. There was no evidence of a difference between groups, *F* (1,108) = .11, *p* = .75. In addition, there was no evidence of a significant interaction between groups and RT Score at 6000ms Delay, *F* (1,108) = .04, *p* = .85. A Means Plot described in Figure 6.16, presents how each group performed in the pre-flight test and post-flight test, with one line representing each group. Participants in the Red Bull group had slightly lower RT scores at 5000ms delay than participants in the water group on both tests.

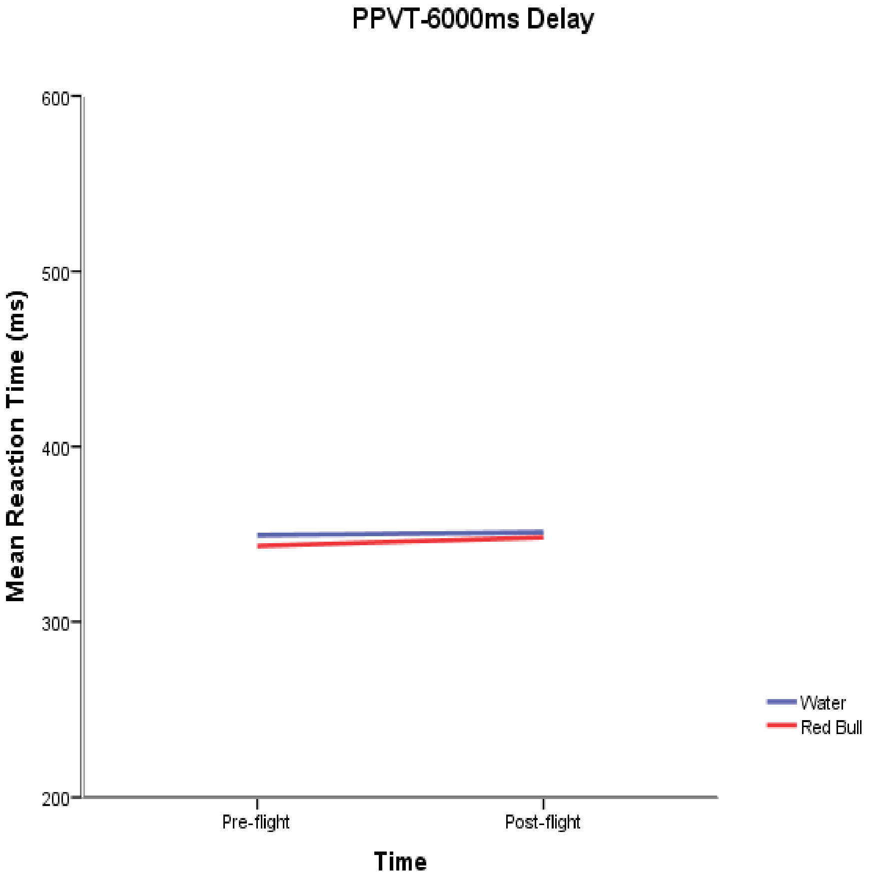

Figure 6.16 Means Plot RT Score at 6000ms Delay

6.10.7 RT Score at 7000ms Delay

A 2 (treatment group: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on RT Score at 7000ms delay. The ANOVA found no evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, *F* (1,108) = .70, *p* = .40, η^2 = .006. There was no evidence of a difference between groups, F (1,108) = 1.12, *p* = .29. In addition, there was no evidence of a significant interaction between groups and RT Score at 7000ms delay, *F* (1,108) = .75, *p* = .39. A Means Plot described in Figure 6.17, presents how each group performed in the pre-flight test and post-flight test, and with one line representing each group.

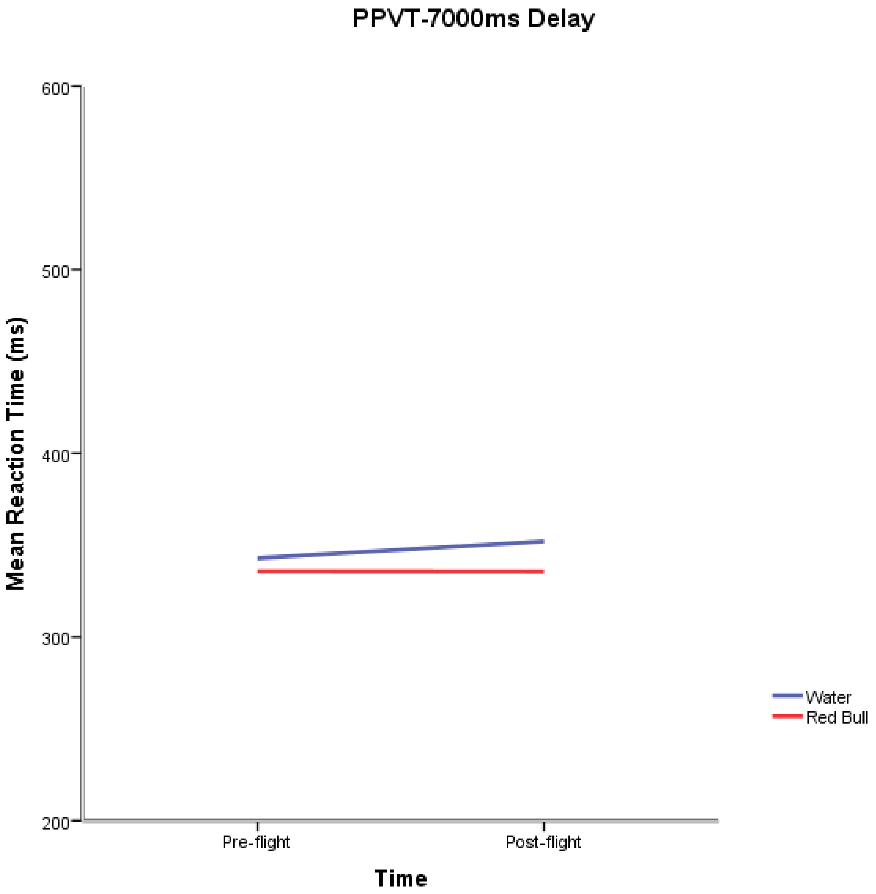

Figure 6.17 Means Plot RT Score at 7000ms Delay

6.10.8 RT Score at 8000ms Delay

A 2 (treatment group: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on RT Score at 8000ms delay. The ANOVA found evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, F (1,108) = 4.02, $p = .04$, $\eta^2 = .036$. There was no evidence of a difference between groups, F (1,108) = .78, $p = .38$. In addition, there was no evidence of a significant interaction between groups and RT Score at 8000ms delay, F (1,108) = .29, $p = .59$. A Means Plot described in Figure 6.18, presents how each group performed in the pre-flight test and post-flight test, with one line representing each group.

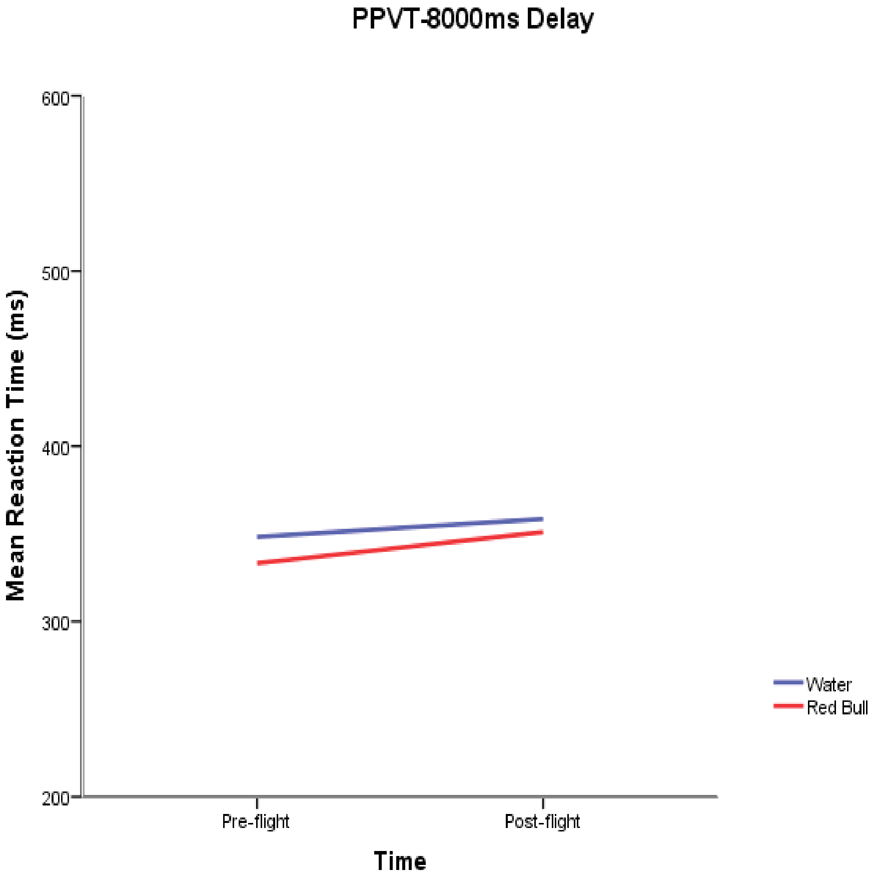

Figure 6.18 Means Plot RT Score at 8000ms Delay

6.10.9 RT Score at 9000ms Delay

A 2 (treatment group: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on RT Score at 9000ms delay. The ANOVA found no evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, F (1,108) = .11, p = .75, η^2 = .001. There was no evidence of a difference between groups, F (1,108) = 1.29, p = .26. In addition, there was no evidence of a significant interaction between groups and RT Score at 9000ms delay, F (1,108) = 1.89, p = .17. A Means Plot described in Figure 6.19, presents how each group performed in the pre-flight test and post-flight test, with one line representing each group. Participants in the water group had an increasing RT scores while participants in the Red Bull group experienced a deceasing RT scores on both tests.

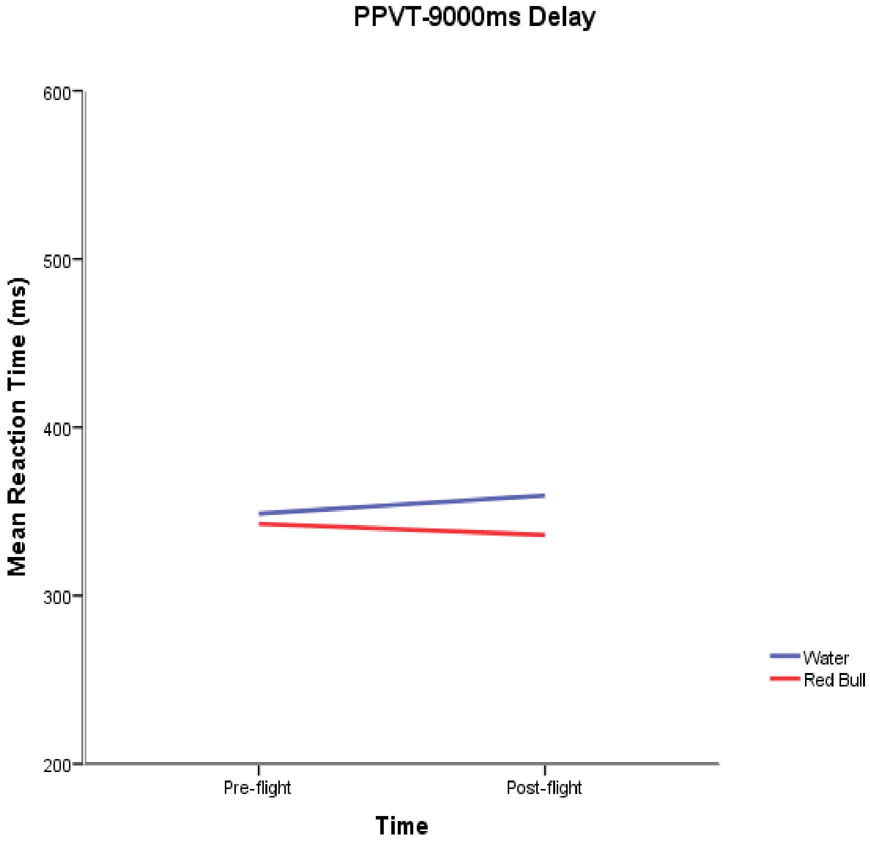

Figure 6.19 Means Plot RT Score at 9000ms Delay

6.10.10 Summary of 1000ms – 9000ms Delays

RT scores ranging from 1000ms to 9000ms delays in the pre-flight test and post-flight test, with one line representing each group can be seen in Figure 6.20 and Figure 6.21. When compared the treatment groups in the pre-flight test, participants in the Red Bull group responded faster than participants in the water group in all nine delays. In particularly, there was an approximately .01 second difference in RT at 1000ms delay between the two groups. At 2000ms and 3000ms delay, participants in both groups performed in similar fashion. At 4000ms delay, participants in the water group appeared to have a noticeable increased RT scores than other delays.

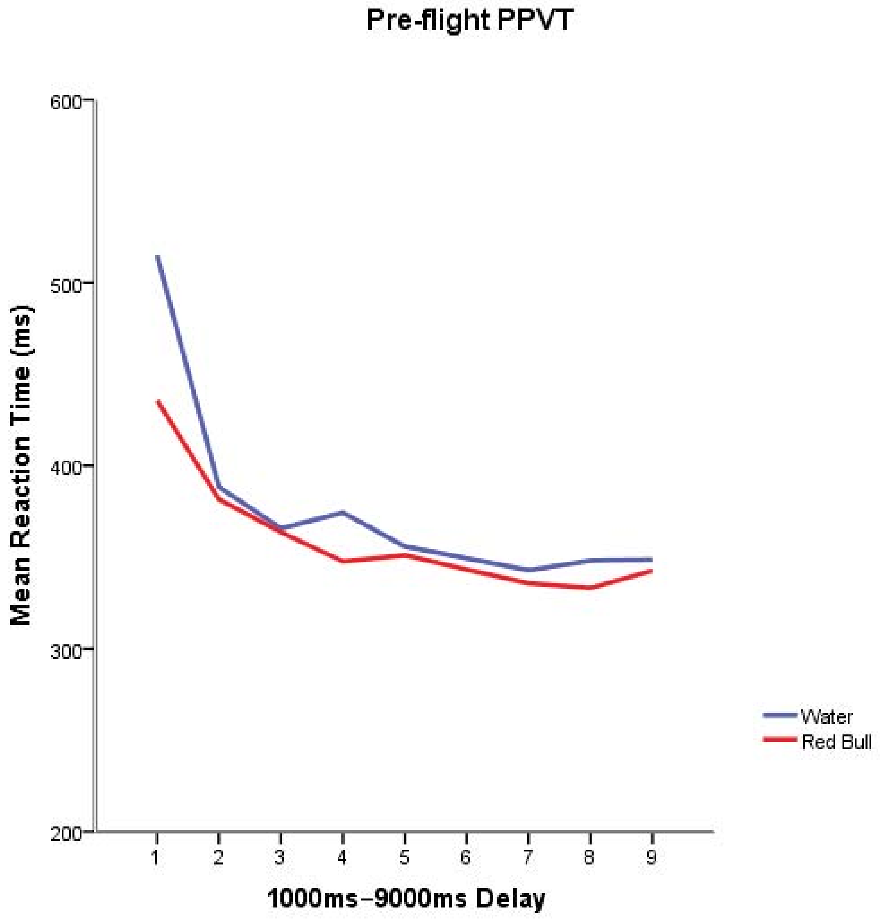

Figure 6.20 Pre-Flight PPVT Results

When compared the treatment groups in the post-flight test, participants in the Red Bull group responded slightly faster than participants in the water group in all nine delays. There was a noticeable difference in RT scores in 1000ms delay. However, this difference was much smaller than the difference in 1000ms delay results in the pre-flight test. Both groups had similar response patterns and shared some close results in the beginning of some delays (e.g., 2000ms delay and 5000ms delay). At 8000ms delay, there was also a noticeable increased RT scores in Red Bull group.

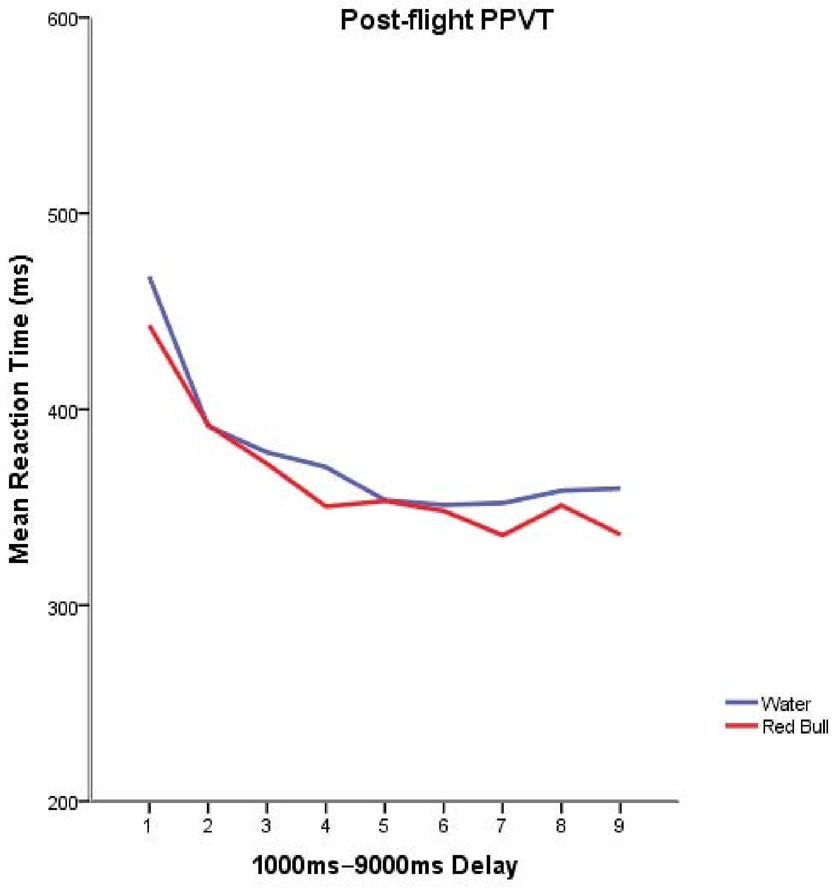

Figure 6.21 Post-Flight PPVT Results

6.10.11 Response Time (RT) Score

A 2 (treatment group: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on Mean RT Score. The ANOVA found no evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, *F* (1,108) = .15, *p* = .70, η^2 = .001. There was no evidence of a difference between groups, *F* (1,108) = 1.06, *p* = .31. In addition, there was no evidence of a significant interaction between groups and Mean RT Score, *F* (1,108) = .24, *p* = .62. A Means Plot described in Figure 6.22, presents how each group performed in the pre-flight test and post-flight test, with one line representing each group. Participants in the Red Bull group had lower Mean RT Score than participants in the water group on both tests.

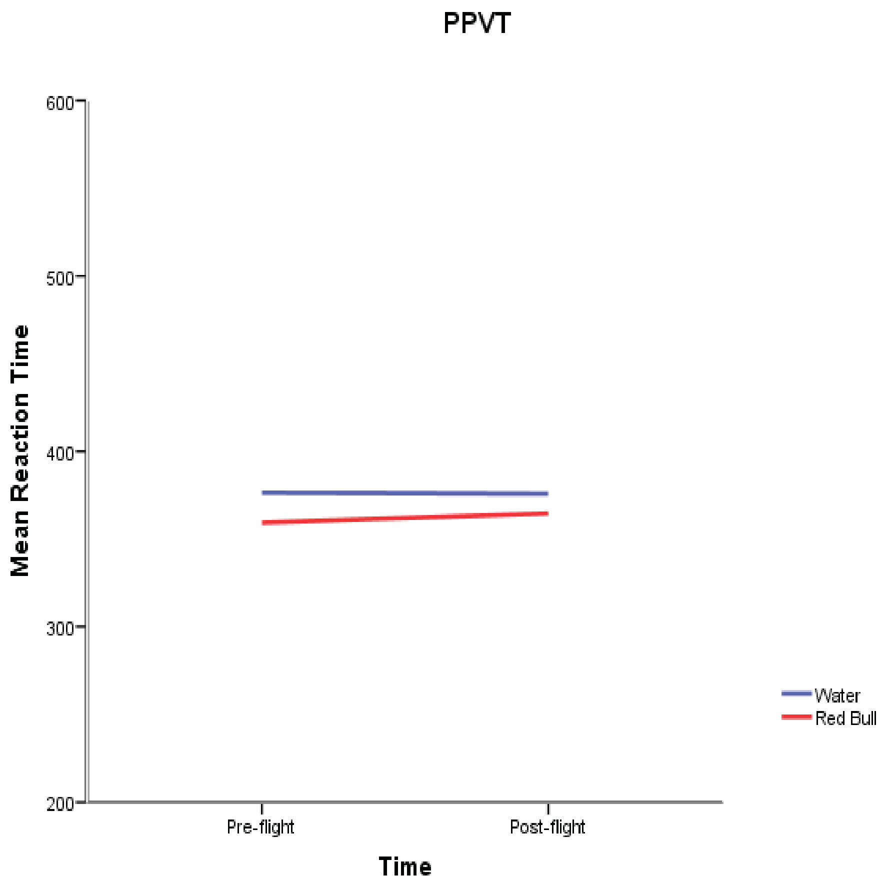

Figure 6.22 Means Plot RT Score

6.10.12 Too Fast Score

A 2 (treatment group: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on Mean Too Fast Score. The ANOVA found evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, F (1,108) = 17.27, p <.001, η^2 = .138. There was no evidence of a difference between groups, F (1,108) = .27, p = .60. In addition, there was no evidence of a significant interaction between groups and Mean Too Fast Score, F (1,108) = .19, p = .67. A Means Plot described in Figure 6.23, presents how each group performed in the pre-flight test and post-flight test, with one line representing each group. Participants in the Red Bull group had lower Mean Too Fast Score than participants in the water group on both tests.

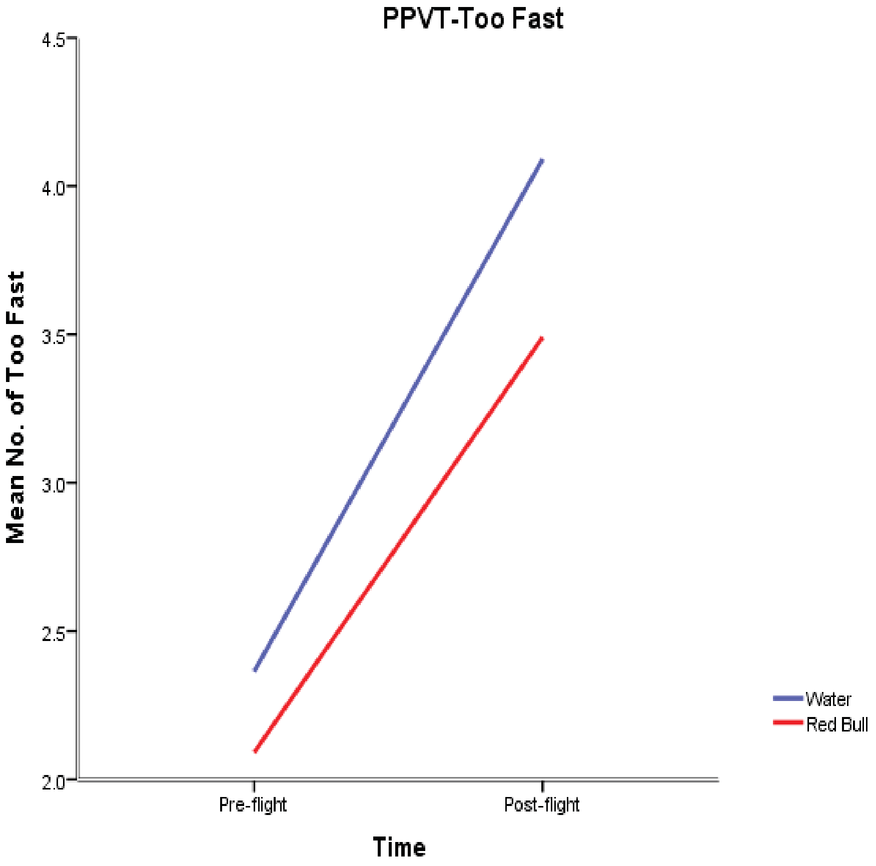

Figure 6.23 Means Plot Too Fast Score

6.10.13 Lapse Score

A 2 (treatment group: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on Mean Lapse Score. The ANOVA found no evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, *F* (1,108) = 1.63, *p* = .21, $\eta^2 = .015$. There was no evidence of a difference between groups, *F* (1,108) = 1.08, *p* = .30. In addition, there was no evidence of a significant interaction between groups and Mean Lapse Scores, *F* (1,108) = .05, *p* = .83. A Means Plot described in Figure 6.24, presents how each group performed in the pre-flight test and post-flight test, with one line representing each group. Participants in the Red Bull group had lower Mean Lapse Score than participants in the water group on both tests.

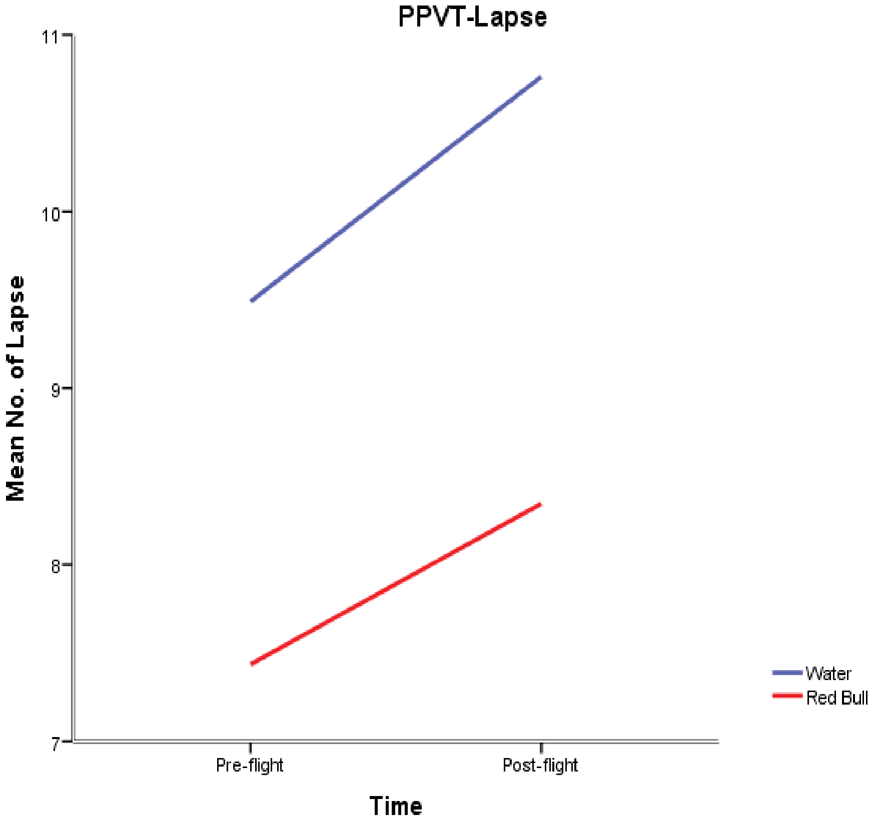

Figure 6.24 Means Plot Lapse Score

6.10.14 Correct Score

A 2 (treatment group: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on Mean Correct Score. The ANOVA found evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, *F* (1,108) = 8.47, *p* =.004, η^2 = .073. There was no evidence of a difference between groups, *F* (1,108) = 1.41, *p* = .24. In addition, there was no evidence of a significant interaction between groups and Mean Correct Score, *F* (1,108) = .22, *p* = .64. A Means Plot described in Figure 6.25, presents how each group performed in the pre-flight test and post-flight test, with one line representing each group. Participants in the Red Bull group had higher Mean Correct Score than participants in the water group on both tests.

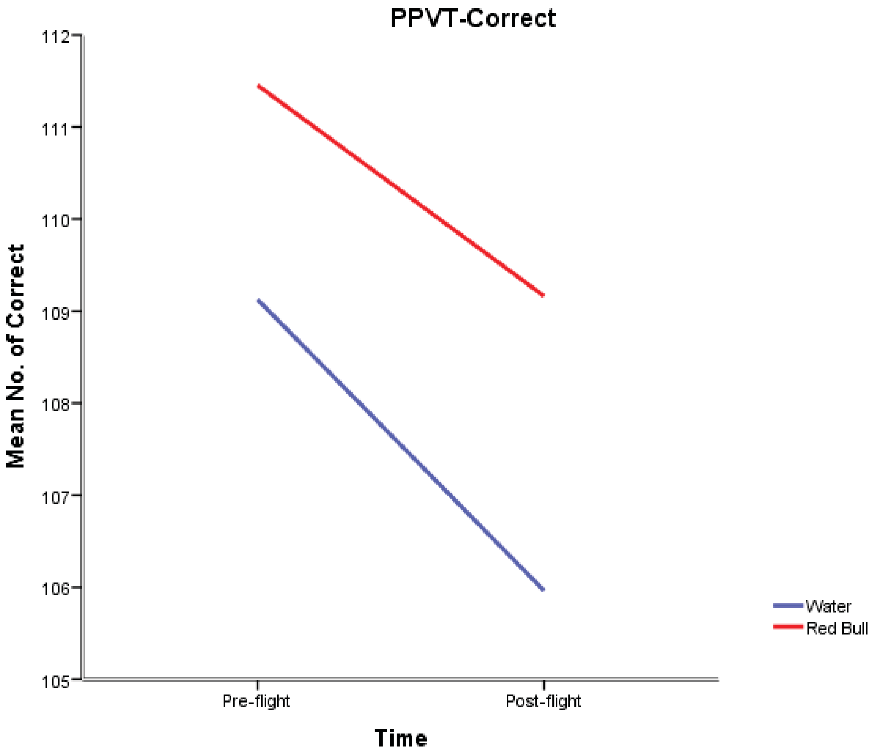

Figure 6.25 Means Plot Correct Score

6.10.15 Sleep Attack Score

A 2 (treatment group: water vs. Red Bull) × 2 (test: pre-flight vs. post-flight) mixed model ANOVA was conducted to compare two groups of participants on Mean Sleep Attack Score. The ANOVA found no evidence of a main effect for the within subjects factors – pre-flight vs. post-flight test scores, F (1,108) = .98, p =.32, η^2 = .005. There was no evidence of a difference between groups, F (1,108) = .98, p = .32. In addition, there was no evidence of a significant interaction between groups and Mean Sleep Attack Score, F (1,108) = .98, p = .32. A Means Plot described in Figure 6.26, presents how each group performed in the pre-flight test and post-flight test, with one line representing each group. Participants in the water group had high mean scores in the pre-flight test and the mean scores were decreased in the post-flight test. Participants in the Red Bull group remained zero Sleep Attack Score on both tests.

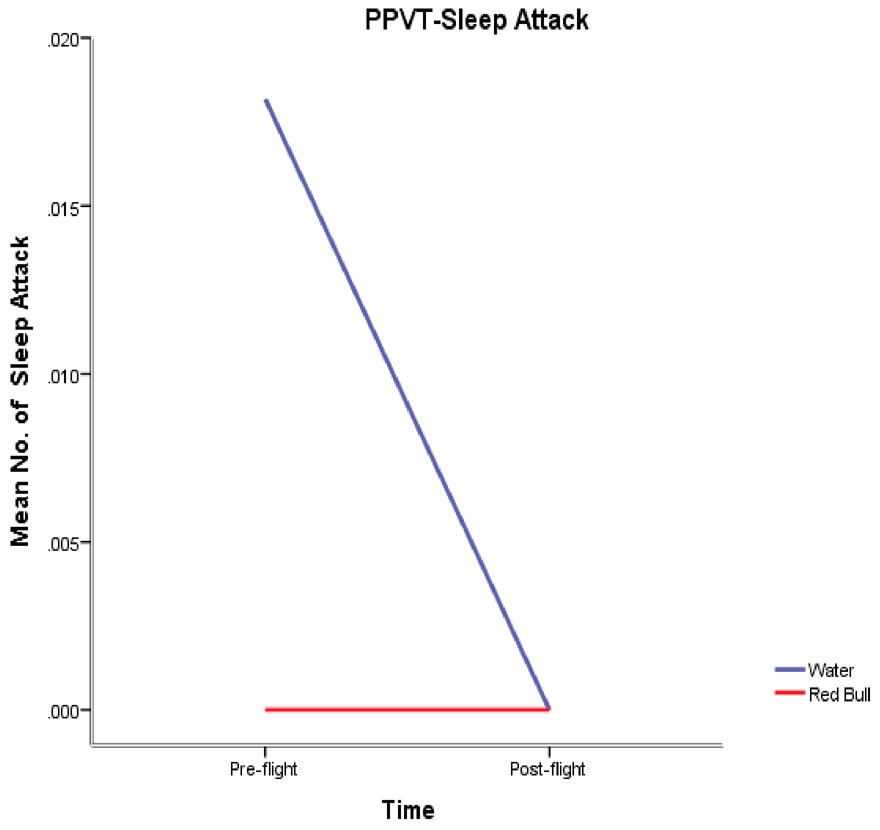

Figure 6.26 Means Plot Sleep Attack Score

6.11 Principle Component Analysis (PCA)

PCA was used to explore two sections of the questionnaire: the pre-flight and the post-flight fatigue test sections. It was considered an appropriate method of identifying underlying structure, and reducing these two sections to a more parsimonious representation of the relationship being measured (Tabachnick, Fidell, & Osterlind, 2001). It had the additional advantage of producing principal component scores that could be used in further analysis of the data. The PCA results of each of these two sections are now presented.

The pre-flight and post-flight fatigue tests form the central component in two relationships. First, concerns with factors that influence the pre-flight fatigue and secondly, the influence of the pre-flight fatigue on the subsequent the post-flight fatigue evaluation. The complexity of these relationships indicated the requirement of using multivariate techniques. The choice of PCA was to reduce the pre-flight and post-flight fatigue responses to a small number of components and to be used in later regression analysis to determine the underlying relationships between the pre-flight and the post-flight fatigue tests.

6.11.1 The Pre-Flight Fatigue

The analysis was carried out in four steps. First the appropriateness of the data for factor analytical technique was evaluated. A correlational matrix was computed for all variables and the presence of correlations greater than .3 determined the likelihood of some underlying processes. The Kaiser-Meyer-Oklin of .831 as a measure of sampling adequacy is described by Kaiser (1974) as “meritorious”. The KMO together with Barlett’s test of sphericity (309.686; $p \leq .001$) established that appropriateness of the data for PCA. In the second step, one component was extracted. To minimise errors in interpretation, each component was described by considering loadings in descending order. The one-factor solution extracted 61.12% of the variance (see Table 6.48). In the third step, orthogonal rotation with varimax was considered for simplicity of reporting. However, due to one component extraction, rotation with varimax was not performed. Finally, component scores were computed for each case using the regression method. Information on the one component is set out in Table 6.49. Positive loadings are given to responses indicating no fatigue, so fatigue is presented by negative scores on this component.

Table 6.48 Total Variance Explained in Pre-Flight Fatigue

Component	Initial Eigenvalues	Total % of Variance	Cumulative %
1	3.67	61.12	61.12
2	.63	10.57	71.69
3	.61	10.21	81.90
4	.56	9.34	91.24
5	.30	4.97	96.22
6	.23	3.78	100.00

Table 6.49 Principle Components Analyses of Pre-Flight Fatigue

Pre-flight Fatigue Items	Component 1
I can concentrate very well.	.86
Mentally, I am well prepared to undergo the flight.	.80
I feel energetic.	.80
I have an overall feeling of tiredness.	-.79
I feel more forgetful than normal.	-.73
I feel mentally exhausted.	-.70
Total % of variance	61.12

6.11.2 The Post-Flight Fatigue

Support for the factorability of the data came from both Bartlett's test of sphericity (142.809; $p \leq .001$) and the Kaiser-Meyer-Oklin measure of sample adequacy (.765). All the variables had a loading greater than .4 and these were grouped in descending order. The one-factor solution extracted 45.09 % of the variance (see Table 6.50). Information on the one component is set out in Table 6.51. Positive loadings are given to responses indicating no fatigue, so fatigue is presented by negative scores on this component.

Table 6.50 Total Variance Explained in Post-Flight Fatigue

Component	Initial Eigenvalues	Total % of Variance	Cumulative %
1	2.71	45.09	45.09
2	.89	14.76	59.85
3	.83	13.79	73.64
4	.71	11.82	85.45
5	.51	8.46	93.91
6	.37	6.09	100.00

Table 6.51 Principle Components Analyses of Post-Flight Fatigue

Post-flight Fatigue Items	Component 1
I can think clearly.	.81
I was well prepared to undergo the flight.	.77
I am pleased with the outcome of the flight.	.67
I feel relaxed.	.62
I feel worn out.	-.62
I find it difficult to concentrate.	-.49
Total % of variance	45.09

6.12 Regression

Standard multiple regression with the post-flight fatigue test as the dependent variable, was performed for three reasons. Firstly, it examined the determinants of fatigue among participants. Secondly, it examined the influence of the pre-flight fatigue test on the post-flight fatigue test. Thirdly, it investigated the influence of treatment on the post-flight fatigue test.

A number of variables were identified as possible influences on the post-flight fatigue test. These independent variables included: time of the day, age, gender, BMI, flying experience, flight duration, treatments, hours of sleep (in the past 24 hours), meal consumed (prior to flying), pre-flight KSS score, the pre-flight fatigue test regression factor score from PCA. Dependent variable is the post-flight fatigue test regression factor score from PCA. Descriptive statistics of dependent and independent variable are presented in Table 6.52.

Table 6.52 Descriptive Statistics of Dependent and Independent Variables

	M	*SD*
Post-Flight Fatigue	.00	1.00
Age	22.45	3.69
Gender	.05	.23
BMI	24.70	3.60
Time	10:00	2:19
Experience	127.57	116.15
Duration	1.38	.64
Sleep	7.32	1.39
Food	.90	.30
Treatment	.50	.50
Pre-Flight KSS	3.62	1.71
Pre-Flight Fatigue	.00	1.00

Gender (0=Male, 1=Female); Treatment (0 = Water, 1 = Red Bull);

Food consumed (0 = No, 1= Yes).

Figure 6.27 presents normal p-p plot of regression standardised residual, which indicated that the assumption that the residuals or error terms were normally distributed. The pattern indicated in Figure 6.28 also confirmed no issues with the assumption that the residuals are normally distributed.

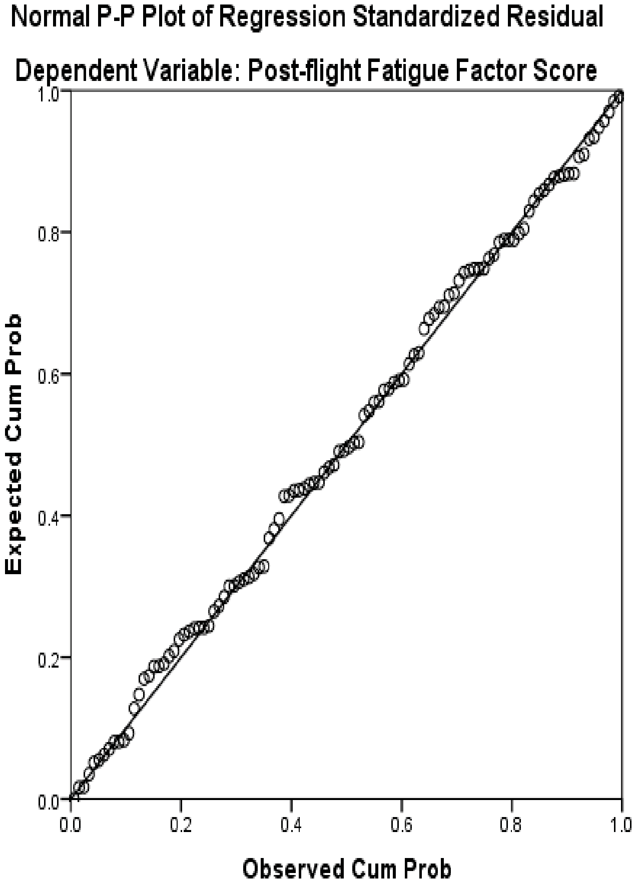

Figure 6.27 Normal Distribution of Residuals - Normality Plot of Residuals

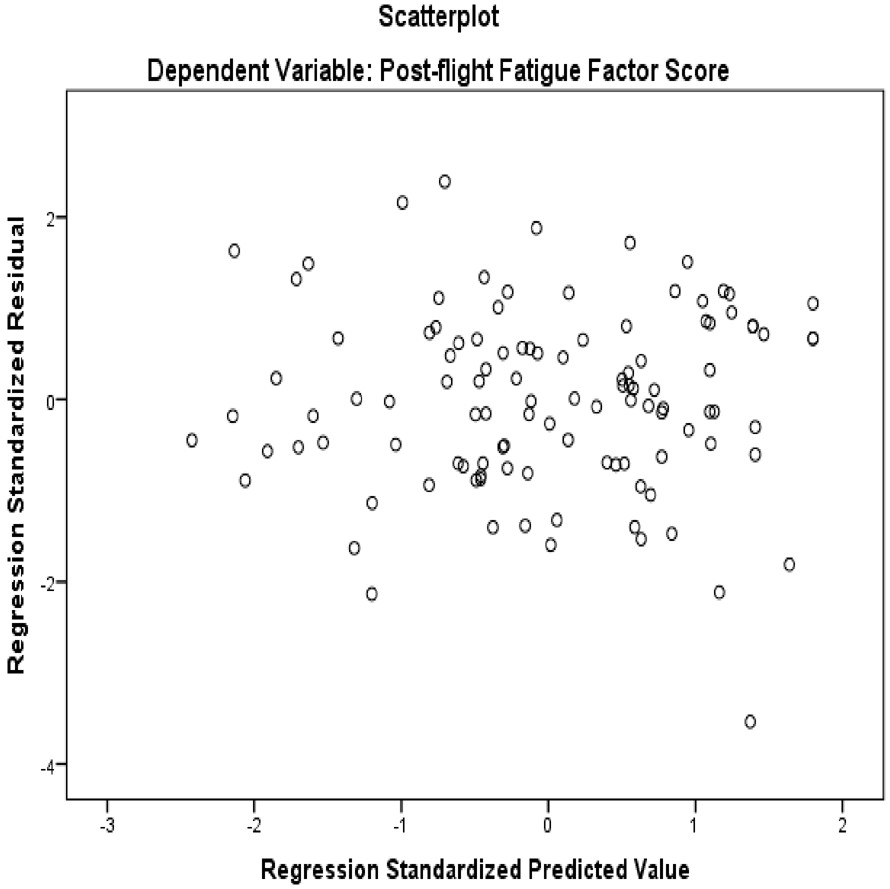

Figure 6.28 Scatterplot: Residuals vs. Predicted

Table 6.53 displays the standardised and unstandardised regression coefficients (beta), the *t* scores and its significance. Pearson correlation and significant value (1-tailed) are presented in Table 6.59. The results of the enter regression analysis suggests that pre-flight fatigue test is the best predictor of the post-flight fatigue, with a standardised beta weight of .53. Next to this is pre-flight KSS and sleep with beta weight of .11 and .09 respectively. The least predictors of the post-flight fatigue are the flight duration and BMI with standardised beta weights of -.16 and -.10. Thus, the multiple regression equation, that involves all the eleven predictors (X_1 to X_{11}) and one dependent variable (Y) i.e., the post-flight fatigue, can be stated as: $\mathbf{Y = .85 - .08X_1 - .06X_2 - .10X_3 + .04X_4 + .01X_5 - .16X_6 + .09X_7 - .07\,X_8 - .05X_9 + .11X_{10} + .53\,X_{11}}$

Table 6.53 Coefficients of Variables

	Unstandardised Coefficients Beta	Std. Error	Standardised Coefficients Beta	*t*	*p*
(Constant) (A)	.85	.97		.87	.39
Age (X_1)	-.02	.03	-.08	-.83	.41
Gender (X_2)	-.28	.41	-.06	-.69	.49
BMI (X_3)	-.03	.03	-.10	-1.09	.28
Time (X_4)	.001	.00	.04	.38	.70
Experience (X_5)	.001	.00	.01	.14	.89
Duration (X_6)	-.24	.18	-.16	-1.35	.18
Sleep (X_7)	.07	.07	.09	1.03	.31
Food (X_8)	-.23	.31	-.07	-.75	.46
Treatment (X_9)	-.10	.18	-.05	-.57	.57
Pre-Flight KSS (X_{10})	.07	.07	.11	.93	.36
Pre-Flight Fatigue (X_{11})	.53	.12	.53	4.28	*

*=p<.001

The regression equation in score form indicates that for every unit increase in time, flying experience, sleep hour, the pre-flight KSS and the pre-flight fatigue, the post-flight fatigue increases by .04, .01, .09, .11 and .53 units, respectively. Whereas, with every unit increase in age, gender, BMI, flight duration, food, treatment, the post-flight fatigue decreases by .08, .06, .10, .16, .07 and .05 units, respectively. The square of multiple R (R^2) being .27 suggests that all eleven predictors collectively account for 27% of the total variance in the post-flight fatigue test score. Table 6.54 is the model summary of the multiple regression. The R^2 and adjusted R^2 values are presented, which are .27 and .19, respectively.

Table 6.54 Model Summary (Enter)

Model	*R*	R^2	Adjusted R^2	Std. Error of the Estimate
1	.52	.27	.19	.90

Table 6.55 presents the test of significance of the model. The model was statistically significant, *F* (11,109) = 3.26, *p* < .001. Thus the finding clearly indicates that the predictor variables like demographic (e.g., time of the day, age, gender, BMI, flying experience, flight duration, treatments, hour of sleep in the past 24 hours, meal consumed prior to flying), pre-flight KSS score and the pre-flight fatigue test score jointly predict substantial variance in the post-flight fatigue test score.

Table 6.55 *F* and *p* (Enter)

Model		Sum of Squares	*df*	Mean Square	*F*	*p*
1	Regression	29.21	11	2.66	3.26	*
	Residual	79.79	98	.81		
	Total	109.00	109			

*=*p*<.001

However, most of the predictors are not individually significant. Therefore, a stepwise regression was performed. Two models were generated: Model 1 and Model 2. Table 6.56 presents the results of the stepwise regression analysis and suggests that the pre-flight fatigue test is the only predictor of the post-flight fatigue test, with a standardised beta weight of .44. In contrast, the pre-flight fatigue test and the flight duration are the predictors of the post-flight fatigue, with standardised beta weights of .44 and -.18, respectively, for Model 2.

Table 6.56 Coefficients of Variables (Stepwise)

		Unstandardised Coefficients Beta	Std. Error	Standardised Coefficients Beta	*t*	*p*
1	(Constant) (A)	-.001	.09		.00	1.00
	Pre-Flight Fatigue (X_{11})			.44	5.1	*
2	(Constant) (A)	.38	.20		1.89	.06
	Pre-Flight Fatigue (X_{11})	.47	.09	.47	5.42	*
	Duration (X_6)	-.28	.13	-.18	-2.08	.04

*=p <.001

Model 1 presents the only one predictor of pre-flight fatigue score. R^2 being .19 suggests that this predictor account for 19% of the total variance in the post-flight fatigue score. The multiple regression equation of Model 1, that involves only one predictor (X_{11}) and one dependent variable (Y) i.e., the post-flight fatigue, can be stated as: **$Y = -.001 + .44\,X_{11}$.**

Model 2 suggests the two predictors: pre-flight fatigue scores and flight duration. R^2 being .23 suggests that these two predictors account for 23% of the total variance in the post-flight fatigue score (see Table 6.57). The multiple regression equation of Model 2, that involves only two predictors (X_6 and X_{11}) and one dependent variable (Y) i.e., the post-flight fatigue can be stated as: **$Y = .38 - .18\,X_6 + .47\,X_{11}$.**

Table 6.57 Model Summary (Stepwise)

Model	*R*	R^2	Adjusted R^2	Std. Error of the Estimate
1	.44	.19	.19	.90
2	.48	.23	.23	.89

Table 6.58 presents the test of significance of Model 1 and Model 2. Model 1 was statistically significant, *F* (1,109) = 26.02, *p* < .001. Thus the finding clearly indicates that the pre-flight fatigue score predict substantial variance in the post-flight fatigue score. Model 2 was statistically significant, *F* (2,109) = 15.57, *p* < .001. The pre-flight fatigue score and the flight duration jointly predict substantial variance in the post-flight fatigue score. The regression coefficient for flight duration was marginally significant (*p* = .04), with a sign that suggests longer flights were associated with greater the post-flight fatigue.

Table 6.58 *F* and *p* (Stepwise)

Model		Sum of Squares	*df*	Mean Square	*F*	*p*
1	Regression	21.16	1	21.16	26.02	*
	Residual	87.84	108	.81		
	Total	109.00	109			
2	Regression	24.57	2	12.29	15.57	*
	Residual	84.43	107	.79		
	Total	109.00	109			

*=*p* <.001

Table 6.59 Pearson Correlation and Significant Value (1-tail

Pearson	Post-flight	Age	Gender	BMI	Time	Experience	Duration	Sleep
Post-flight	1.00	-.09	-.06	-.14	-.05	.06	-.11	.17
Age	-.09	1.00	-.07	.22	.26	-.20	.32	-.02
Gender	-.06	-.07	1.00	-.14	.16	.06	-.10	.06
BMI	-.14	.22	-.14	1.00	.12	.01	.03	-.08
Time	-.05	.26	.16	.12	1.00	-.09	.51	.20
Experience	.06	-.20	.06	.01	-.09	1.00	-.42	-.07
Duration	-.11	.32	-.10	.03	.51	-.42	1.00	.08
Sleep	.17	-.02	.06	-.08	.20	-.07	.08	1.00
Food	-.06	.12	-.05	.22	.24	-.07	.18	.08
Treatment	-.10	-.10	-.16	.11	-.05	.03	.02	-.14
KSS	-.26	-.05	.12	.08	-.05	.11	-.15	-.22
Pre-flight	.44	.10	-.14	-.02	.06	-.08	.14	.18
Sig.(1-tailed)								
Post-flight	.	.16	.27	.07	.30	.28	.12	.04
Age	.16	.	.22	.01	.00	.02	.00	.43
Gender	.27	.22	.	.07	.05	.27	.15	.26
BMI	.07	.01	.07	.	.11	.47	.37	.21
Time	.30	.00	.05	.11	.	.16	.00	.02
Experience	.28	.02	.27	.47	.16	.	.00	.24
Duration	.12	.00	.15	.37	.00	.00	.	.21
Sleep	.04	.43	.26	.21	.02	.24	.21	.
Food	.27	.10	.29	.01	.01	.22	.03	.21
Treatment	.16	.15	.05	.13	.31	.36	.40	.07
KSS	.00	.29	.10	.21	.32	.12	.06	.01
Pre-flight	.00	.14	.08	.42	.26	.21	.07	.03

Chapter Seven:Discussion

7.1 Introduction

This chapter discusses the findings of the study and their implications and applications to student pilots and flight training organisations. The aim of this study is to investigate the effects of consuming Red Bull energy drinks on student pilot fatigue and performance levels. Findings in relation to age, gender, training environment, sleep habits, energy drink consumption, subjective and objective measures of fatigue and alertness are listed in the following sections.

7.2 Participants’ Age, Experience, Performance and Fatigue

No correlation between participants’ age and their fatigue and performance ratings was found in this study. Overall, the results of PPVT tests and KSS ratings were similar between all age groups regardless of what drinks they had consumed. Some older participants (age: 30–39) in the water group performed just as well as younger participants (age: 17–19 or age: 20–29) in the Red Bull group in PPVT tests. Three age groups of participants were all competent in PPVT performance. KSS ratings were also alike between three age groups. In contrast, Blatter et al. (2006) found that younger participants (age: 20–31) sustained better performance than the older participants (age: 57–74) in PPVT tests and a flattening of PPVT performance curve for the older participants was observed. No correlation between participants’ flying experience, fatigue and performance ratings was found. In contrast, Steptoe and Bostock (2012) found Captains were more likely to report regular in-flight compromise owing to fatigue than First Officers. Experienced pilots were likely to experience in-flight fatigue more than inexperienced pilots. These aforementioned studies have indicated the different outcomes compared to the findings of the present study. Further research to investigate the effects of age, flying experience on student pilot fatigue and alertness levels is warranted.

7.3 The Relationship between Gender and PPVT Performance

No correlation between gender and PPVT performance was found. The number of female pilots was significantly less than the number of male pilots. Participants' reaction times (RTs) seemed to be normal and the differences of RTs were quite similar between gender. According to Beijamini, Silva, Peixoto, and Louzada (2008), gender can be a factor when evaluating RTs in PPVT performance. They observed an influence of gender in PPVT performance in adolescents. Gender had a significant effect in mean RTs in both PPVT tests in their study. Their results indicated that the RTs of men were faster than those of women. They also identified that there was significant gender difference in the number of lapses. Men had fewer lapses compare to women. One of the reasons for this difference could be that women adopt different strategies for test resolution. Blatter et al. (2006) also confirmed that PPVT performance was dependent on gender; women tend to avoid false starts while men tend to focus on being as fast as possible. The average number of false starts was less in women than in men. Similarly, Blatter et al. (2006) observed that women had tendencies to inhibit their PPVT responses to maintain accuracy more than men. However, no significant gender difference in the number of lapses was found in their study.

The lack of a relationship between gender and PPVT performance determined by the present study would suggest that male and female participants all indicated high vigilance performance levels compared to other participants in other studies (Loh, Lamond, Dorrian, Roach, & Dawson, 2004; Mueller & Piper, 2013). However, further research is warranted to establish the relationship between gender and PPVT performance among student pilots.

7.4 The Relationship between FTOs' Culture and Pilot Fatigue

Some participants seemed to be at ease in a comfortable and positive environment for training and learning. Geographically, some FTOs have better weather conditions throughout the year. Consequently, more flights can be scheduled for participants in these FTOs, and their training programmes are less likely to be affected by weather. Participants and flight instructors appeared more satisfied and relaxed than in some other FTOs.

Different operational policies might have adverse effects on pilot fatigue and alertness levels. Some FTOs required their students to arrive two-hours earlier than their scheduled training time. In some instances participants arrived at 6:00 am at the FTO to prepare for a 7:30 am start-up in order to meet their 8:00 am scheduled booking for take-off. Other FTOs required their students to arrive 30 minutes earlier than their scheduled time. Discussing the logistics of flight scheduling is beyond the scope of this study. However, some students in some FTOs have expressed dissatisfaction with the former practice. The results of the present study indicated that the earlier the arrival time at FTOs, the more fatigued and less motivated participants appeared. This is also confirmed by Gander et al. (1994). They found that the earlier a subject went on duty, the lower his activation levels by the end of the duty day. The later a subject came off duty, the higher he rated his fatigue levels. The longer a subject remained on duty; the more negative effects could affect him.

Unpredictability of the training schedule is another issue among student pilots and FTOs. Some contributing factors to this issue was identified, such as environmental factors (e.g., weather), human factors (e.g., instructor unavailability) and aircraft factors (e.g., aircraft unavailability). A review of this issue should be investigated in further studies.

7.5 The Relationship between Off-Training Employment and Pilot Fatigue

The present study indicated that 12% of participants had either a full-time or a part-time job along with their training. It is not unreasonable for a young, healthy, motivated student pilot to work up to a total 80 hours per week (e.g., 50 hours of training and 30 hours of working after training) (Lei & Ruishan, 2011). However, safeguards against fatigue should be implemented by the student pilots who choose to engage in employment during their flight training. Perhaps some participants avoided a *Yes* answer out of concern that they would be pressured to stop their off-training job. It is likely that on-training fatigue can be induced by off-training employment. These participants could be carrying additional fatigue during their training. Despite the low significant job status of the participants, no differences in alertness and fatigue were found in this study. A review of this issue should be examined in further studies.

7.6 In-Flight Micro-Sleep Occurrences among Student Pilots.

In-flight micro-sleep occurrences were prevalent in this study. It can become a constant safety factor when pilots are flying. This is supported by several previous studies

(Caldwell et al., 2009; Taneja, 2007). Gregory et al's (2010) results indicated that 32% of pilots had experienced micro-sleep on duty; however, it was considered a rare occurrence. In-flight evaluations have indicated that micro-sleep often occurs among pilots. This study offers some valuable preliminary data on micro-sleep occurrences among student pilots. The prevalence of poor sleep quality was high among participants, which could be the contributing factor to in-flight micro-sleep occurrences. The results indicated that 52% of participants extended their normal hours of wakefulness from the average of 16 to 19 hours. Participants appeared to be incurring sleep debt during the training week that they repaid during the weekend or off training days. It was clearly indicated that they sleep more in weekends or in off-training days than training days. The prevalence of poor sleep quality in participants appeared to be similar to other college students in other studies (Roach, Petrilli, et al., 2006). This finding was also supported by Taneja (2007) and Gander and Signal (2008). In Gander and Signal's study, their results indicated that 38.9% of study samples reported sleeping ≤ 6 hours per day and 25.3% reported longer sleep latency (≥ 30 minutes) in training days. Similarly, Gander et al.(1996) described that laboratory studies have demonstrated that reducing sleep by two hours on one night was sufficient to significantly decrease subsequent alertness and performance. They found that for each one hour less sleep obtained by participants, the likelihood of an error to occur in PPVT increased by 20%.

The present study has suggested that sleep loss accumulates over time into a cumulative sleep debt. These findings indicated that the relationships between acute sleep loss, a cumulative sleep debt, and poor sleep quality could produce poor performance or micro-sleep occurrences. Overall, participants with shorter sleep performed worse, making more errors in PPVT tests. Their ability to meet training requirements may be influenced by the amount of hours they sleep. Further research is warranted to establish the relationship between sleep quality, in-flight micro-sleep occurrences and PPVT performance among student pilots.

7.7 Napping, Caffeine Use and Fatigue Countermeasures.

The implementation of napping has become the most effective fatigue countermeasure in aviation (Caldwell, 2005). It offers some possible benefits to student pilots. However, napping and resting facilities in FTOs may prove to be difficult to resolve. The results of this study indicated that participants did not have the opportunity to nap during the day. Participants have placed napping low on the list of pilot fatigue countermeasures, whereas the use of caffeine was high.

In this study, tea and coffee were more frequently consumed than energy drinks. In particular, the older age group of participants (age: 30–39) consumed far less energy drinks than the young participants. Some participants often employed this fatigue countermeasure to reduce their sleepiness levels. In addition, it is used significantly higher in younger participants. Similarly, Roach, Dawson, et al. (2006) found that 34% of 18–24 years old were regular consumers of energy drinks in their study. Further research is warranted to establish the relationship between consumption of caffeinated drinks and fatigue countermeasure management in student pilots.

7.8 The Relationship between Energy Drink and Alcohol Consumption

The prevalence of energy drink consumption in participants appears to be similar and consistent to other college students in other studies. They also shared some common reasons for consuming energy drinks. The finding of consumption of the mix of alcohol and energy drinks was common among participants in the present study. This finding is supported by Bliss and Depperschmidt (2011) and Roach, Dawson, and Lamond (2006).

7.9 Energy Drink Consumption and Vigilance Performance.

80mg of caffeine in one energy drink did not have significant results in improving participant vigilance performance levels. This finding was supported by Loke (1988), Caska and Molesworth (2007) and Molesworth and Young (2008). Loke did not detect any effects of caffeine at 80mg and even higher doses on vigilance or reaction time. Caska and Molesworth (2007) found that caffeine in low (1mg/kg[19]) and moderate (3mg/kg) dosages failed to improve pilots' ability to fly an instrument landing approach on a flight simulator. Molesworth and Young (2008) failed to reveal any differences in pilot performance and the consumption of caffeine with different amount (0mg/kg, 3mg/kg and 5mg/kg of caffeine). In contrast, Lieberman, Wurtman, Emde, Roberts, and Coviella (1987) found caffeine in doses of 32mg, 64mg, 125mg and 256mg significantly improved auditory vigilance and visual reaction time in their research. Jay, Petrilli, Ferguson, Dawson, and Lamond (2006) found that a smaller amount of caffeine within energy drinks could produce the same alertness effect as a higher amount of caffeine. Similarly, Reyner and Horne (2002) detected that 250ml Red Bull energy drink containing 80mg caffeine offered the same improvements to performance as 200mg caffeine. Inconsistencies in the results of previous studies could be due to different methodologies and their statistical process.

Like caffeine alone, other active ingredients in an energy drink may also impact on subsequent daytime sleep, in both its quality and duration. Low dose caffeine intake is

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[19] 1mg/kg: 1mg of caffeine per 1 kg of participant's body weight (Caska & Molesworth, 2007).

associated usually with pleasant changes in mood and performance. Caffeine intake can also have negative effects on the body. Some individual participants in the Red Bull group reported more regular use of the toilet than usual after their flights. This was due to the diuretic action of caffeine. There was one participant in the Red Bull group, who felt sick after the flight. The cause of this was not investigated.

When compare to caffeine alone, the advantage of energy drinks is the fixed amount of caffeine dosage. However, caffeine content within coffee can differ depending on the amount of coffee is used or the methods of making coffee. In that case might make energy drinks more suitable especially for those who are sensitive to caffeine effect. Further research is warranted to establish the relationship between the amount of caffeine and its negative effects and vigilance performance among student pilots.

7.10 The Relationship between Pre-Flight and Post-Flight Fatigue

There is a discernible pattern in that higher levels of pre-flight fatigue cause higher levels of post-flight fatigue for participants. A positive correlation between them was found. Student pilots have largely been neglected in studies in relation to fatigue and sleep loss created by the flight training regime. A clear link is established between pre-flight and post-flight fatigue among participants in this study. It is consistent with the finding of Neville, Bisson, French, Boll, and Storm (1994) who suggested that fatigue was related to recent (48 hours) cumulative flight and sleep history. In addition, Armentrout, Holland, Toole, and Ercoline (2006) suggested that the combination of chronic fatigue with acute fatigue could further degrade pilots' abilities to integrate information.

7.11 KSS Score, Flight Durations and Energy Drink Consumption.

It was expected that participants who flew a longer duration flight would be more fatigued, less alert and have higher KSS Score than those who flew a short duration flight. This prediction was not supported in this study. Small improvements in KSS Score were observed in some of the short flight duration flight. However, it was not a significant finding. In contrast, Steptoe and Bostock (2012) suggested fatigue was more prevalent in pilots who had experienced higher than average objective work demands. Pilots who flew more were significantly more likely to be fatigued. In contrast, Anne Eriksen and Akerstedt (2006) found there were significant interaction effects between morning and evening flights and time for KSS Score on both the outward-bound and the homeward-bound flights. Reyner & Horne (2002) found 250ml of Red Bull energy drinks improved KSS Score and reduced sleep-related driving incidents during the afternoon in young adults. They also suggested a regular can of Red Bull, containing 80-mg caffeine and other ingredients was much more effective than coffee with the same amount of caffeine. This confirmed the earlier work of Lieberman et al. (1987) and indicated that consumption of caffeinated beverages may be important in maintaining performance efficiency and well-being.

80mg of caffeine within the energy drink indicated no effects on KSS Score. Smith (2002) suggested 40 mg of caffeine could influence mood and performance. In particularly, it improved alertness and aspects of performance. In contrast, Smit and Rogers (2000) found the significant effects of 12.5mg caffeine on cognitive performance. Similarly, Leino et al. (2007) suggested that a moderate 200mg dose of caffeine did not have a significant effect on flight performance during a maximum of 30 hours of sleep deprivation. Further research is warranted to establish the relationship between the amount of caffeine and the flight durations and KSS Score among student pilots.

7.12 The Relationship between Energy Drink Consumption and Pilot Fatigue

It was expected that participants who consumed Red Bull energy drinks would be less fatigued and more alert at the post-flight phase than those who consumed bottled water. The correlation between fatigue and energy drink consumption failed to reach significance. Thus, the null hypothesis of no relationship between student pilot fatigue and energy drink consumption to improve fatigue and alertness levels cannot be rejected. This is consistent with previous studies, which found energy drink consumption had no effect on fatigue levels (Bliss & Depperschmidt, 2011). However, some studies disagreed with this finding (Lieberman et al., 1987). The reason for the discrepancy is not clear, although it may reflect different composition of energy drink ingredients or the timing of tests in relation to drink consumption. The repeated performance of certain tasks under the influence of fatigue may lead to a ‘learned’ tolerance. It is possible that pilot performance may not be impaired by fatigue whilst they are engaged primarily in familiar tasks, but their performance might deteriorate significantly when faced with unexpected circumstances.

Participants reported the flight phase that produced the most fatigue was the en-route phase. Fourty one per cent of participants stated that the en-route phase was where the most fatigue was recorded, followed by 20% pre-flight planning and 15% approach/landing. The descent phase recorded least levels of fatigue and followed by the take-off phase. This finding agrees with a recent study by Gregory et al. (2010).

7.13 The Relationship Between Student Pilots and PPVT Performance

A minority of participants repeatedly complained about the long and continuous nature of the PPVT. Previous studies have suggested that the ten-minute PPVT test is commonly used in laboratory and field work. It assesses the impact of sleep loss, sustained wakefulness, and time of day on neurobehavioral performance. In aviation studies, PPVT has become a ‘gold standard’ for measuring fatigue objectively (Basner & Dinges, 2011). The logic behind the PPVT is that if fatigue leads to a lapse of attention, it should be reflected by slow responses to changes in the stimulus event. This study used PPVT as an objective measure tool because it is methodologically reliable and relatively versatile (Lopez, Previc, Fischer, Heitz, & Engle, 2012).

A computer-based version of the ten-minute PPVT test was used in this study. Generally, longer performance tests are more sensitive to the effects of fatigue than shorter tests (Lamond et al., 2008). They suggested that the shorter task was not quite as sensitive to performance lapsing as the ten-minute task, especially when two to ten second delay periods were used and/or when the levels of sleep loss and fatigue were more severe than usual. Similarly, Basner and Dinges (2011) suggested that the ten-minute PPVT was a highly reliable time length with intra-class correlations for key metrics such as lapses measuring. In contrast, Roach, Dawson, et al. (2006)found that performance on the ten-minute PPVT was more highly correlated with the five-minute PPVT than the 90-second PPVT. They suggested that the five-minute PPVT data might provide a reasonable substitute for the ten-minute PPVT in circumstances where a test for less than ten minutes would be required. Some previous studies have adopted longer tasks (Smit & Rogers, 2000). They used the 20-minute simple reaction time task in their study.

Participants may be more motivated to perform shorter tasks. However, motivation can counteract the detrimental effects of fatigue and decrease the sensitivity of such tasks (Roach, Dawson, et al., 2006). In this study, the ten-minute PPVT was more practical and appropriate within the aviation training environment. It would be difficult to demonstrate any reliable changes in performance during short-term sleep loss among participants using tasks that were shorter than ten minutes. However, tasks are longer than ten minutes would be more fatiguing and would not be suitable within the time-constrained aviation environment. Further research is warranted to establish the relationship between student pilot attitude and the length of PPVT.

Chapter Eight:Conclusions and Recommendations

8.1 Conclusion

Student pilots can compromise their cognitive and physical performance levels when they are fatigued. It is widely recognised that pilot fatigue and sleep loss have critical effects on the safety margins in aviation, especially when student pilots are unwilling or unable to admit their conditions to their flying instructors or operational staff (Caldwell, 2005). “Can-do”, “Macho” attitudes and underestimating the degree of fatigue are not uncommon among pilots (Miller et al., 2005). Meanwhile, safety can be further affected by fatigued pilots when the incorrect fatigue countermeasure strategies are implemented.

It is reported that consuming energy drinks can increase energy, alertness levels, and decrease fatigue levels among the millions of consumers around the world (Aniţei, Schuhfried, & Chraif, 2011). These kinds of perceptions do exist in the aviation community (Miller et al., 2005). It is not uncommon to adopt this strategy in combating fatigue and sleep loss among some pilots, especially young pilots. However, the swift change in public perception of energy drinks from mild stimulant to lethal is unprecedented (Sepkowitz, 2013). Some pilots may be unaware of the amount of caffeine they are ingesting in energy drinks. They need to be aware of the danger of caffeine overdoes and the appropriateness of consuming energy drinks to combat sleepiness, and boredom under an aviation training environment (e.g., in the cockpit).

The question as to when it is not safe to operate an aircraft after consuming energy drinks is a more difficult one to answer. Firstly, there is no established recommended daily allowance for caffeine. Secondly, on the basis of scientific research and the calculations in this study, less than 500mg of caffeine per day is generally considered safe daily dose (Sepkowitz, 2013; Thelander et al., 2010). This is equivalent to 6.25 cans of Red Bull energy drinks (250ml per can). However, other studies recommended no more than 200–300mg of caffeine per day for adults and less than 100 mg per day for adolescents (Jackson et al., 2013; Seifert, Schaechter, Hershorin, & Lipshultz, 2011). This is equivalent to 2.50 – 3.75 cans of Red Bull energy drinks for adults and less than one and half cans for adolescents. In contrast, Caldwell (2003) suggested a daily dosage limit of 800mg of caffeine. This is equivalent to ten cans of Red Bull energy drinks. To reach the possible lethal dose of 3g of caffeine (James, 2012; Thelander et al., 2010), a student pilot would need to ingest at least 37.5 cans of Red Bull energy drinks within a few hours (80mg of caffeine per serving), which equivalents to 9.38 litres or almost 40 cups of Red Bull energy drinks. Thirdly, results may vary from person to person and depend on body size, age, sex and genetic factors. Lastly, the content of energy drinks vary by product and additional ingredients may confer toxicity.

8.2 Limitations

This present study is not without limitations. It should be noted that the sample was largely homogeneous in relation to gender (94.5% male and 5.5% female). The first limitation of this study is the lower number of female participants. However, imbalanced gender ratios are characteristics of flight training organisations.

Secondly, this study was conducted in the autumn and winter season. It is possible that the consumption of energy drink patterns of student pilots might not reflect their consumption of energy drinks during the entire flight training period. In particularly during summer season training, increased energy drink consumption may have more adverse effects (e.g., student pilots are more likely to be dehydrated in the summer and will drink more).

Thirdly, the present study asked participants to report their fatigue and alertness levels, sleeping history, energy drinking behaviours retrospectively, which may result in self-report bias. Possible confounding influences might affect these results and deserve attention when interpreting the present findings. The sleep and fatigue data and KSS ratings are subjective, and thus subject to the possibility of bias. In addition, the ratings of fatigue were made at different times of day and may have been influenced by circadian variations in fatigue and prior sleep loss.

A minority of participants often checked their watches during PPVT tests. Factors such as having knowledge of task duration may have confounded or affected the results. Some participants may have used this strategy for maintaining performance based on the knowledge that the task was 10 minutes long. This finding is supported by Loh et al. (2004).

Some participants found that a standard computer keyboard with multiple keys could interfere with PPVT performance, which increases the error rates. A customised keypad such as the type found on the Palm PPVT device would have been superior and produced less error.

PPVT performance can be affected by many factors other than the characteristics of the participants performing the test. These include hardware, programming of the PPVT, and definitions for calculating PPVT outcome metrics. In this respect, the PPVT is not well standardised. For example, simple PPVT outcome metrics were used in this study: mean RT, lapse, too fast, correction, sleep attack, which have been used in the previous studies. However, more complex metrics have been used in other studies. For example: mean response speed (1/mean RT) × 1,000 was used by Lamond et al. (2008). Fastest 10% of RT, lapse percentage, and slowest 10% of RT was used by Loh et al. (2004).

A further limitation is that the testing situation itself may not have helped to detect the effects of energy drink consumption on alertness and fatigue levels among student pilots. Actual fligh may have increased arousal levels, and effects of caffeine (e.g., improvement in alertness) cannot be detected in situations of high arousal, but only in situations of low arousal.

8.3 Recommendations

This study is the first of its kind to examine the effects of consuming Red Bull energy drinks on fatigue and performance levels among student pilots in New Zealand. Student pilots might ingest high doses of caffeine and other stimulants unknowingly placing themselves in high risk situations. The following list indicates that a careful approach to energy drink consumption in aviation is recommended and caution should be exercised:

1. The lack of experimental data of energy drink consumption amongst student pilots;
2. The lack of long-term follow up of student pilots energy drink consumption;

3. The inconclusiveness of the long-term health effects of energy drink consumption;
4. And the absence of universally recommended daily intake guidelines for energy drinks.

Studnt pilots should be warned about the dangers of poor sleep quality should be cautioned among student pilots. It can result in serious cardio, metabolic and psychiatric problems that may influence a student’s quality of life and safety of flight operations (Karlen et al., 2010). In addition, sleep problems are associated with lower academic performance and negative health issues (Lohsoonthorn et al., 2012). A general course on sleep, nap, sleep hygiene, fatigue, and fatigue countermeasures should be taught during the Human Factors Training phase cosnducted by FTOs. Student pilots would be benefit from knowledge of sleep loss and how to recover from sleep loss. Information about the use of diet, exercise to promote healthy sleep patterns should be available to student pilots.

Fatigue management and awareness training should be made available to operational schedulers, and management teams. The results indicated that operational staff were failing to notice the effects of social and behavioural trends among student pilots. This suggested a lack of understanding of the impact that flight training has on the well-being of student pilots. A general lack of knowledge about pilot training scheduling and rest policies indicates an issue that need to be addressed. Flight schedulers should reduce the need for student pilots to reportin in on off-days. More efficient fatigue management system should be used to help address the fatigue and sleep problems reported by student pilots.

8.4 Future Work & Research

Research in respect of energy drink and caffeine consumption and their effects on human fatigue, performance and alertness has been investigated in depth. However, many of the results remain inconsistent and many aspects of this area remain neglected, in particular, among student pilots. The following list suggests some of the possibilities:

1. Relatively little is known about student pilot energy drink consumption, their pattern of consumption, its effects and temporal relationship to their flying performance.
2. Only a small number of studies have investigated perceptions and attitudes of student pilots towards energy drinks and flying.
3. Are their identifiable characteristics, which allow prediction of student pilots most at risk from fatigue-related accidents?

The results seem to indicate that it would be worthwhile to follow up the present study with a larger one, in which data could be collected for longer periods of time from other FTOs in New Zealand. The aim would be investigate additional effects, such as the effects of season, geographical location, and poor weather conditions. Also, it would be valuable to study a variety of flight conditions, such as departure and arrival times throughout the day, body position, scheduled versus non-scheduled napping, sleep length before flight, caffeine and nicotine intake.

A more accurate examination of the effects of energy drink consumption and the use of a battery of performance tests are needed to eliminate any extraneous variables. For example, Electroencephalographic (EEG) recording or Actigraphy data (Jay et al., 2006;

Reyner & Horne, 2002) could be used to assess sleepiness of individual participants in any future study.

The FTOs need to recognise that there is a complex relationship between pilots fatigue and pilots schedules, how they impact on each other and safety in aviation. For pilots, fatigue and sleep disturbance have both important short-term and long-term consequences for safety and health. Pilots often used caffeine as a performance enhancer, to mitigate the effects of fatigue during the critical stages of flight (e.g., flight planning and preparation). Typically this is administered through the consumption of coffee, tea and energy drinks. In this safety sensitive context, it is not energy drink dependence that causes concern; it is the timing and quantity of consumption that determines whether or not problems will emerge. Aviation safety still depends heavily upon “faultless” human performance.

The data from this study is important for understanding student pilot fatigue and alertness levels in flight training, understanding effectiveness of energy drinks as a fatigue countermeasure, and identifying effects of poor scheduling on flight performance.This study represents an effort to contribute knowledge to the New Zealand aviation community about the dangers of student pilot fatigue, along with emphasise of the appropriate role of energy drink consumption in attenuating this danger.

In conclusion, this study is the first of its kind to examine the effects of Red Bull energy drink consumption on student pilots in New Zealand. It suggests that the consumption of Red Bull energy drink prior to flight training did not have significant impact on student pilot fatigue and alertness levels in their subsequent training flight. The findings of this study do not form any dietary recommendations for student pilots. Further studies with larger samples sizes with good gender homogeneity and increased doses are warranted.

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Appendices

APPENDIX A

Questionnaire

QUESTIONNAIRE INSTRUCTIONS FOR ALL SECTIONS:

Please tick in the box next to the answer of your choice or write in the space provided.

There are no right or wrong answers. Please choose the answer which represents ***your opinion.***

Example One:

Are you?
Male ☑
Female ☐
Example Two:

Age: ___*18*___

COMPLETION AND RETURN OF THE QUESTIONNAIRE IMPLIES CONSENT.

THIS IS AN ANONYMOUS QUESTIONNAIRE

Procedures are to complete the following tests.

Pre-flight test:

1. Section 1
2. Computer based test- PPVT

Post-flight test:

1. Section 2 and computer based test - PPVT
2. Section 3, 4 and 5.

Researcher’s Note:

Time:

Date:

Water/Energy Drink

THIS IS AN ANONYMOUS QUESTIONNAIRE

SECTION 1 — Pre-flight

Which type of cockpit display will be used for upcoming flight?
Analogue ☐
Glass cockpit ☐

Which type of aircraft will be used for the upcoming flight? ______________________

Please name the lesson which you will be completing for the upcoming flight,

e.g.,“low flying”:____

Please provide details of ANY medication consumed within the past 24 hours:

Name/type: __________________ Time consumed: _____________________

Name/type: __________________ Time consumed: _____________________

Please indicate the time of meal consumed in the past three hours (INCLUDING light snacks):

Time consumed: ____________________

Type (breakfast, lunch, light snacks) __________________

How many hours of sleep did you have in the past 24 hours? _____________________

Likert-Scale Statements	Strongly disagree						Strongly agree
Mentally, I am well prepared to undergo the flight	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
There are new concepts or techniques featuring in the flight	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
I feel energetic	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
I feel more forgetful than normal	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
I can concentrate very well	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
I have an overall feelings of tiredness	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
I feel mentally exhausted	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐

Likert-Scale Statements	Strongly disagree 1	2	3	4	5	6	Strongly agree 7
The flight will mostly be revision of concepts and techniques that I am already familiar with	☐	☐	☐	☐	☐	☐	☐

This is the Karolinska Sleepiness Scale shown below, which will be used to reveal your fatigue or your sleepiness during each session.

How sleepy are you now—at this stage of questionnaire?	
1 = extremely alert	☐
2 = very alert	☐
3 = alert	☐
4 = rather alert	☐
5 = neither alert nor sleepy	☐
6 = some signs of sleepiness	☐
7 = sleepy, no effort to stay awake	☐
8 = sleepy, some effort to stay awake	☐
9 = very sleepy, great effort to keep awake	☐

SECTION 2 —Post-flight

How long was the flight? ________ hours

Likert-Scale Statements	Strongly disagree						Strongly agree
I am pleased with the outcome of the flight	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
I was well prepared to undergo the flight	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
I find it difficult to concentrate	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
I can think clearly	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
I feel relaxed	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
I feel worn out	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐

Likert-Scale Statements	Strongly disagree						Strongly agree
There was a high workload throughout the flight	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
I found it easy to recall important points and concepts relating to the training flight	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
My performance gradually decreased throughout the flight	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
My performance sharply decreased near the end of the flight	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
I would be able to perform at the same level of proficiency on another similar training flight to be commenced now	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
I would be able to perform at a higher level on another similar training flight to be commenced now	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
I became easily distracted at times near the end of the flight	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
I made small mistakes or forgot things at the start of the flight	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
I made small mistakes or forgot things near at the end of the flight	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐

Likert-Scale Statements	Strongly disagree						Strongly agree
My flying ability improved over the course of the flight	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
I was able to maintain a focus on the requirements of the training flight throughout its duration	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐

Likert-Scale Statements	Strongly disagree						Strongly agree
Energy drinks have an effect on a student pilot’s ability to pilot an aircraft	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
Energy drinks are an effective and safe method to increase a student pilot’s mental and physical performance	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
Student pilots should not consume an energy drink on same day they operate an aircraft	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐

How sleepy are you now—at this stage of questionnaire?	
1 = extremely alert	☐
2 = very alert	☐
3 = alert	☐
4 = rather alert	☐
5 = neither alert nor sleepy	☐
6 = some signs of sleepiness	☐
7 = sleepy, no effort to stay awake	☐
8 = sleepy, some effort to stay awake	☐
9 = very sleepy, great effort to keep awake	☐

SECTION 3 — Demographics

Age: ________
Weight: ________ (kg)
Height: ________ (cm)
Total flight time in your logbook: _______hours
Ethnic group: __________________________

Are you?
Male ☐
Female ☐

Are you a smoker?
Yes ☐
No ☐

Female ONLY: Are you pregnant?
Yes ☐
No ☐

Are you currently on ANY medication?
Yes ☐
No ☐

Do you currently hold a job in addition to your flight training?
Yes, I currently hold a full-time Job (more than 35 hours per week) ☐
Yes, I currently hold a part-time Job (less than 20 hours per week) ☐
Yes, I currently hold a part-time Job (less than 10 hours per week) ☐
No ☐

Do you have a current New Zealand Medical Certificate?
Yes, I have a class one. ☐
Yes, I have a class two. ☐
No ☐

Which of following PPL and/or CPL theory exams have you passed?

PPL theory:
Air Law ☐
English Language Proficiency ☐
Flight Radio Telephony ☐
Human Factors ☐
Meteorology ☐
Air Navigation and Flight Planning ☐
Aircraft Technical Knowledge ☐

CPL theory:
Air Law ☐
Meteorology ☐
Flight Navigation ☐
General Aircraft Technical knowledge ☐
Principles of Flight ☐
IFR - Flight Navigation ☐
IFR - Instruments and Navigation Aids ☐

Have you consumed energy drinks in the past 24 hours?

Yes ☐

No ☐

SECTION 4 — Sleep and Fatigue

Estimate your usual bedtime________ and wake time________ when you are doing flight training.
Estimate your usual bedtime________ and wake time________ when you are not doing flight training (e.g., weekends)
How long does it usually take you to fall asleep at night? ________ minutes
Estimate your usual number of caffeinated drinks per day:
Coffee_________
Soft drinks_________
Tea _________
Estimate you daily consumption of nicotine (e.g., cigarettes) __________
How many times do you usually awaken during a typical night sleep?
1 ☐
2 ☐
3 ☐
4 ☐
5 or more ☐

Do you often nap to supplement your main sleep period?
Yes ☐
No ☐

Rate your usual sleep when you sleep at night
1 = poor ☐
2 = fair ☐
3 = good ☐
4 = very good ☐
5 = excellent ☐
Rate your usual sleep when you sleep during the day
1 = poor ☐
2 = fair ☐
3 = good ☐
4 = very good ☐
5 = excellent ☐

How manageable is it to remain alert during a usual flight lesson?
1= very difficult ☐
2 = difficult ☐
3 = neutral ☐
4 = easy ☐
5 = very easy ☐

How many times have you fallen asleep in the cockpit while flying?

0 ☐
1 ☐
2 ☐
3 ☐
4 ☐
5 or more ☐

In what way has fatigue affected your flight performance?

Could not concentrate ☐
Alertness degraded ☐
Performance degraded ☐
Other ☐

When your flight performance is affected by fatigue, which phase of flight performance is affected?

Pre-flight planning ☐
Pre-flight/walk-around ☐
Engine start/taxi ☐
Take-off ☐
Enroute ☐
Descent ☐
Approach/landing ☐
Engine shutdown ☐

SECTION 5—Energy Drink Consumption

Which of the following brand of energy drinks have you consumed in the past 12 months? (select all that apply)

Demon Energy Drink ☐
Pure Energy Energy Drink ☐
Monster Energy Drink ☐
Mother Energy Drink ☐
Nos Energy Drink ☐
Red Bull ☐
Rockstar Energy Drink ☐
V Vitalis Energy Drink ☐
Lift Plus Energy Drink ☐
Please name other brands________________________________ ☐
None ☐

How many energy drinks do you consume per week?

0 per week ☐
1-3 per week ☐
4-6 per week ☐
7-9 per week ☐
10 or more per week ☐

Have you consumed energy drink on the same day that you piloted an aircraft?

Yes ☐
No ☐

In what circumstances do you consume energy drinks?

I need more energy in general ☐
Driving automobile (extended period) ☐
Study for exam/complete homework ☐
Sleep deprivation ☐
I mix them with alcohol when I am partying ☐
Piloting aircraft (extended period) ☐
Peer/social pressure ☐
Others ☐

Please enter in the number of cans or bottles of energy drinks that you have consumed in one DAY without experiencing side effects? (Jolt and crash episodes, headache, heart palpitations, etc.)

Number of cans or bottles

Demon Energy Drink (568ml Mega Can) ________
Pure Energy Energy Drink **(568ml Mega Can)** ________
Monster Energy Drink **(550ml Can)** ________
Mother Energy Drink **(500ml Can)** ________
Nos Energy Drink (568ml Mega Can) ________
Red Bull (250ml Can) ________
Red Bull Sugar Free **(250ml Can)** ________
Red Bull (330ml Bottle) ________
Red Bull (355ml Can) ________
Red Bull (473ml Can) ________
Rockstar Energy Drink **(500ml Can)** ________
V Vitalis Energy Drink **(250ml Can)** ________
V Vitalis Energy Drink Sugar Free **(250ml Can)** ________
V Vitalis Energy Drink **(350ml Bottle)** ________
V Vitalis Energy Drink **(355ml Can)** ________
V Vitalis Energy Drink **(500 ml Can)** ________
V Vitalis Energy Drink **(500 ml Bottle)** ________
Lift Plus Energy Drink **(250ml Can)** ________
Lift Plus Energy Drink **(355ml Bottle)** ________
Lift Plus Energy Drink **(500ml Can)** ________
Others

Likert-Scale Statements	Strongly disagree						Strongly agree
Consumption of energy drinks is considered similar to consumption of coffee	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
Jolt and crash (no/low energy) episodes are typical after consumption of energy drinks	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
Headaches are common after consuming energy drinks	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
Heart palpitations (pounding or racing) are common after consuming energy drinks	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
Energy drinks have no effect on short term memory	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
Chronic use of energy drinks can lead to other use of stimulants	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
The consumption of energy drinks can be associated with risky or behaviour problem	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐
I feel effectively energised after consuming energy drinks	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐

THANK YOU FOR COMPLETING THE QUESTIONNAIRE

YOUR TIME IS MUCH APPRECIATED

APPENDIX B

Student Hand-Outs

Dear pilots

I am currently doing a small research on pilot fatigue during training as a part of my masters. Your experience as a pilot is highly valuable and will help in understanding more about fatigue in aviation. Your participation in this research will have a positive effect and would be much appreciated.

The research will consist of a briefing, two small tests prior to flying, and two small tests after flying, and it won’t take much of your time.

I will start collecting data soon, so I will approach you on a day you are scheduled to fly. Meanwhile I am here all of the time, so feel free to ask me any questions you may have.

Again, your participation would be positive and much appreciated, and I thank you in advance.

Libo

L.yang3@massey.ac.nz
0272122141
School of Aviation
Massey University

APPENDIX C

FTO Email

Dear

Thank you for your interest in my research. My name is Libo Yang and I am currently completing the Master degree in Aviation at Massey University, Palmerston North. The research is about pilots' performance under the influence of energy drinks before and after their flights. It exams whether there will be any effects on their performance levels and their fatigue levels after consuming the energy drinks. The goal of this research is to determine if energy drinks help can to reduce pilots' fatigue levels. The research will be requiring a number of voluntary student pilots from your flight training organisation. No specific requirements in regards to their age, gender or race.

There are some prerequisites for those student pilots are listed below:

1. They should be conducting solo flights
2. They should be conducting their flights between 0700am and 1200pm
3. The length of their flights should not exceed 2.5 hour
4. Their lessons should be at a similar or same level of difficulties

These are the procedures that I will be following on the days of testing and data collecting:

1. Brief student pilots about the research, ethics, etc.
2. Ask for consent to participate in the research;
3. Give them the questionnaire and allow them to complete it;
4. Ask them to do the computer test;
5. Then, allocate pilots to Water or Red Bull randomly;

6. After the flight, ask them to do the computer test ;
7. Then give them the questionnaire and allow them to complete it.

Testing and data collecting should be completed within 25 minutes prior to the flight and within 20 minutes after the flight. Red Bull (250ml) or bottled Water will be consumed during the test. In order to utilise the morning time more effectively, 2 or 3 student pilots will be conducting research tests at the same.

It would be greatly appreciated if you could arrange and advise the dates to conduct the research among your student pilots within 1 week time frame in the following month.

Ethics Disclaimer

This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher named above is responsible for the ethical conduct of this research.

If you have any concerns about the conduct of this research that you wish to raise with someone other than the researcher(s), please contact Professor John O'Neill, Director, Research Ethics, telephone 06 350 5249,email: humanethics@massey.ac.nz.

Kind regards

Libo Yang

Master Student

Massey University