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Article

Understanding Factors Underlying Fatigue among Collegiate Aviation Pilots in the United States

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Abstract: An increase in evidence-based studies into the deleterious effects of fatigue on flight operations has been reported by key aviation groups globally. The collegiate aviation flight training environment has not been researched at the same level when compared to military and airline operations. College aged students are unique in the sense that they are tasked with classwork, studying, participation in student organizations, social activities, and often have part time jobs within and outside of the academic environment. These conditions may cause errors, incidents, accidents, poor academic performance, and undesirable health metrics. The purpose of this study was to understand fatigue as a multi-factorial dimension and to assess potential relationships among these factors using hypothesized measurement models. The research team distributed the Collegiate Aviation Fatigue Inventory II (CAFI-II) to eight small, medium, and large collegiate aviation programs in the United States. The CAFI-II primarily focuses on fatigue awareness, causes and symptoms of fatigue, and lifestyle choices. Four hundred and twenty-two (n = 422) valid responses were obtained. Results suggested a direct predictive relationship between fatigue in collegiate flight training and the perceptions of respondents of conditions that are known to cause fatigue. Findings also suggested that respondents who had a favorable perception of fatigue risk and management programs had a better understanding of the causes of fatigue.

Keywords: collegiate aviation; human factors; fatigue

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1. Introduction

Fatigue has been identified as a safety hazard that has the potential to reduce the optimal performance required of aviation professionals such as pilots [1]. Fatigue as a construct is defined by the International Civil Aviation Organization (ICAO, Montreal, QC, Canada) as a "reduction of mental state or physical performance that results from sleep loss, extended wakefulness, an excessive workload, and or poor lifestyle choices" [2] (p. 3). The results of these undesirable conditions may reduce alertness and the ability to safely operate an aircraft or perform safety-related duties. The National Transportation Safety Board (NTSB, Washington, DC, USA), which is the aviation accident investigation and safety analysis entity in the United States, has included reducing fatigue-related accidents on its 'most wanted' list since 2016 [3]. To reduce the risk of fatigue-related safety events, the NTSB board recommends addressing the problem through comprehensive research, education, and training [3].

Aviation stakeholders with safety oversight functions such as the Federal Aviation Administration (FAA, Washington, DC, USA) and other organizations that advocate for aviation safety have produced copious amounts of literature on fatigue and its detrimental effects on human performance [3–5]. Despite this plethora of literature on fatigue risk for the larger aviation community, there seems to be a gap in literature specific to the collegiate aviation community. The FAA has guidance on fatigue risk management for maintenance technicians [6]; Part 121—airline carrier operations [7]; Part 135 "on-demand" operations [8]; Flight Attendants [9]; and fatigue risk management systems broadly for aviation safety [10]. There is guidance on fatigue that broadly targets the general aviation community [4,11], but this does not specially address the scope and complexity of the collegiate aviation flight training community. There are minor provisions that require evaluation of aviation safety risks such as fatigue in the airmen certification standards (ACS) for civil pilot applicants, but this is inadequate to deal with the complexities of fatigue risk awareness and management in collegiate aviation flight training [12].

Recently, there have been some provisions for fatigue risk management among certificated providers through the Federal Aviation Regulation (FAR) 117, but this does not address most of the nuanced operations of the collegiate flight training environment [13]. The only regulation that pertains to "duty time" for collegiate aviation pilots is FAR 61.195. This regulation limits instructor flight time to eight hours per 24-h period. This is a positive fatigue mitigation strategy [14]. Nevertheless, as recommended by the extant literature on fatigue and its effects on human performances in aviation, a multifaceted approach beyond prescriptive regulations, which includes education and training [10,15] as well as evidence-based fatigue management systems [5,16], is needed to mitigate these effects during flight operations.

Collegiate aviation pilots in the United States, including many flight instructors, are full-time students seeking higher education degrees [17]. In addition to completing university courses, these pilots are expected to participate in extracurricular activities such as sports and student organizations. Moreover, they often have part-time jobs to support themselves. All the aforementioned are known factors that may limit these pilots' sleep quality and quantity opportunities, increase their workload, and negatively impact their lifestyles [18–20]. From a research perspective, previous fatigue studies have mostly focused on military and/or commercial aviation operations [16,21,22]. There is a need for more studies that comprehensively unravel the underlying structures of fatigue and its safety risk in collegiate aviation flight training to fill the gaps identified. Refs. [5,20,23–25] recommend that fatigue mitigation strategies should be based upon scientific principles and knowledge obtained from research studies.

Research indicates that external and internal factors such as workload, stress, organizational pressures, and environmental conditions may influence fatigue levels. Further, recognizing the onset of fatigue may be insidious [26]. Moreover, lifestyle choices such as eating healthily, sleep hygiene, getting enough exercise, and work life balance are important factors that can mitigate the cause and effects of fatigue [18,27]. As part of an empirically based approach to understanding fatigue, [5] recommends five primary methods for data collection techniques: self-reported measures, survey, performance data, research studies, and the analysis of time worked.

1.1. Research Problem

There have been recommendations for more evidence-based studies into the deleterious effects of fatigue on flight operations globally and the need for effective fatigue risk management strategies aimed at improving safety [3,28]. Additionally, there has been a need for continuous monitoring and safety improvements within the aviation industry coupled with efforts to minimize general aviation accident rates by both the NTSB [3] and the FAA [29]. While Safety Management Systems (SMS) including Fatigue Risk Management Systems (FRMS) are proactive in nature, SMS is not mandated for Collegiate Aviation Flight programs in the United States. An evidence-based approach to understanding fatigue and its associated safety risks in the collegiate flight environment falls in line with these objectives of the FAA and the NTSB. In summary, there is a gap in extant research that addressees the unique challenges of understanding and managing fatigue in U.S. collegiate aviation flight operations. There is also a need to use an evidence-based approach to identify mitigation strategies that will improve collegiate aviation operational safety in line with the FAA and NTSB objectives. This study provides an opportunity to close gaps identified in previous studies and advance fatigue related research in aviation.

1.2. Research Objectives

The overall purpose of this study was to understand fatigue as a multi-factorial dimension in collegiate aviation operational environment and to assess the validity and reliability of scale items that measure these factors using first-order Confirmatory Factor Analysis (CFA). A hypothesized measurement model was used to validate hypotheses that suggest predictive relationships between the factors and the over-arching dimension Fatigue. The strength of predictive relationships between the factors and the over-arching dimension Fatigue was also assessed. Specifically, Structural Equation Models (SEM) used IBM AMOS® to assess the predictive relationships between the three underlying factors (causes of fatigue, fatigue awareness, and lifestyles) and fatigue. Finally, there was a need to evaluate how various demographic variables influenced survey item responses on the factors underlying fatigue. Independent sample t-test and simple Analysis of Variances (ANOVA) were used to assess the differences in mean scores of responses provided by various demographic groups on the three factors underlying fatigue. In summary, specific objectives derived from the generic research goal are outlined below:

1. Assessing the relationships between measurement items that underlie factors within the dimension of fatigue in collegiate aviation.
2. Understanding the strength of relationships between three measured constructs (causes of fatigue, reported fatigue symptoms, and lifestyle choices among collegiate aviation pilots) and the overarching dimension of fatigue in collegiate aviation operations.
3. Examining the variations in responses and perceptions by surveying items based on demographics (Academic Level, Pilot Certification, and Gender) and their effect on the measured constructs underlying fatigue in collegiate aviation operations.

A rationale for the reliability and construct validity assessment of the survey instrument "Collegiate Aviation Fatigue Inventory I" (CAFI-I) previously used to measure fatigue in collegiate aviation flight programs [30] was due to textual modifications made to some of the scale items to reflect a more diverse collegiate flight population, and also the larger sample size in this study which provides an opportunity for a more robust psychometric assessment aimed at improved reliabilities of scale items and validity of constructs, therefore providing the collegiate aviation pilot community more evidence of the research instrument's utility.

A review of the extant literature focused on the links between fatigue and aviation safety and understanding of the theoretical dimension of fatigue in aviation, and identification of current gaps in studies related to fatigue in the collegiate aviation environment was carried out. The objective of the review was to lay out a theoretical framework and empirical justification for this study.

2. Fatigue and Aviation Safety

Pilot fatigue is a significant problem in the aviation industry [26,31,32]. Though the accident rate has declined, the general aviation sector accounts for many aircraft accidents when compared to scheduled-service and military aviation [29]. According to the Aircraft Owners and Pilots Association (AOPA, Frederick, MD, USA) [33], during the last ten years, approximately 73% of all non-commercial fixed-wing GA accidents had a human error listed as a probable cause or contributing factor. It is important to note that instructional flight activity accounts for approximately 14% of GA aircraft accidents.

Accident investigators have useful resources, methods, and guidance to establish the causal factors leading to aircraft mishaps [5]. Nevertheless, the most thorough investigations may lack the evidence to establish fatigue as a probable cause [16] even though it could have been present. Additionally, very often, aircraft accidents involving small GA aircraft are not as thoroughly investigated as those involving air carriers [34].

Considering the deleterious effects of fatigue, the difficulty in listing it as a probable cause by accident investigators [27,32,35,36], and that more than 80% of aircraft accidents are attributable to human factors [4], it is plausible that fatigue has been a contributing factor to GA aircraft accidents at a higher than reported rate. Fatigue has often been suggested as a key human factor issue that indirectly contributes to GA safety events and results in substantial damages to aircraft and severe injuries to people [34].

The extant literature suggests multiple fatigue risk primers and antecedents such as low-quality sleep, insufficient hours of rest, boredom, physical and mental exertion, poor lifestyle choices, excessive workload, and disrupted circadian rhythms [37,38] can have adverse effects on effective task completion, and in aviation that is worrying. Some of these adverse effects of fatigue on task completion provoke significant performance degradation in higher order thinking and reaction-time [26,27,37].

One of the most effective strategies to mitigate the safety risk associated with fatigue is good quality sleep. The National Sleep Foundation provides guidance on metrics for good quality sleep including sleeping for more time while in bed (at least 85% of the total time), falling asleep in 30 min or less, waking up no more than once per night, and being awake for 20 min or less after initially laying down for sleep. These, among others, are the primary determinants of good quality sleep [39].

According to ICAO [5], sleep is vital for restoring the body and brain of individuals. Even though there is no single solution to prevent fatigue during flight activities, research has also indicated that certain strategies, which should include a healthy lifestyle, can enhance safety and productivity if correctly applied [21,31]. Prescriptive flight and duty times are simplistic defensive measures to mitigate fatigue in aviation since they generally do not take individual, organizational, and other differences into account [40]. Moreover, fatigue regulations have failed to adequately incorporate empirical data on fatigue, sleep, and circadian disruption, among other factors [41].

Despite this, a prescriptive approach, i.e., reliance on strict compliance with regulations to mitigate fatigue in aviation, is necessary since it helps pilots determine if they are fit for duty prior to a flight [5,42]. Other effective fatigue mitigation measures include the use of hypnotics [21], strategic use of caffeine [1], and fatigue training and education [20,42]. In addition, lifestyle choices such as proper nutrition and regular fluid intake, consistent physical activities, and effective workload management can mitigate the effects of fatigue in flight operations and ensure the wellness of aviation professionals such as pilots [42,43].

2.1. Fatigue Research in a Collegiate Aviation Environment

Collegiate aviation programs accredited by the Aviation Accreditation Board International (AABI. Opelika, AL, USA) are important sources for producing professional pilots in the aviation workforce in the United States, especially after the Public Law, 111-216 went into full effect in 2013 [44]. Therefore, it is imperative to understand and assess the quality of training and education, including fatigue identification and management, for these pilots at such formative stages of their professional lives. Such assessments can help to structure curriculum and training course outlines that turn out safety-conscious professional pilots for the aviation industry.

As previously mentioned, in the United States, most fatigue studies have focused on military [22,45,46] and/or commercial operations [16,45,47–49] without bridging the gap to collegiate aviation. However, there has been a recent effort by researchers to better understand fatigue during flight training [17,19,20,25,30,50]. Findings from the recent studies listed in the preceding paragraph suggest that fatigue compromises aviation safety in collegiate aviation operations. The conditions are further exasperated by inadequate sleep and academic, social, and work demands. These factors invariably affect the healthy sleep hygiene and good nutrition of pilots. External pressures such as organizational demands and internal pressures to meet performance criteria also contribute to a high prevalence of fatigue in some collegiate flight operations.

In a study on safety culture in a collegiate aviation program in the U.S., a researcher found out that international flight students in the aviation program had different perceptions of fatigue risk management as compared to domestic U.S. flight students [23]. The international students, comparatively, had a less favorable perception on how fatigue issues were handled in the collegiate aviation program. The differences in the mean of Likert-scale item "Management schedule CF's as much as legally possible", with little concern for sleep schedules or fatigue, was statistically significant [t (128) = −4.48, $p = 0.05$ (2T)].

The study also found a significant positive predictive relationship between scale item "reporting for flight duty when fatigued because they perceived they had no choice" and the outcome variable "not bothering to report near misses or close calls in flight training activities". This is indicative of the potential adverse effect of fatigue on voluntary reporting of safety events in collegiate flight programs. The study advocated for a proactive peer to peer accountability for safety to reduce the potential risky behavior of flying while fatigued.

Additionally, in another study, researchers utilized fatigue related decision-making scenarios. Each participant, undergraduate students enrolled in a Midwest Part 141 collegiate aviation flight program, was presented with six scenarios that had a combination of mental and/or physical fatigue factors, lack of sleep and or stress [25]. The participants were asked to provide go-no-go decisions.

Results of the qualitative analysis found that participants struggled to articulate desirable alternatives to scenarios that clearly should have no-go decisions. For instance, almost half of the 35 participants said they would take a night flight after a 14-h day which included mentally and physically fatiguing events.

Additionally, findings suggested that, even though there were obvious undesirable fatigue levels, participants were more likely to express a go-decision particularly if an instructor was on-board. This study provided evidence that improved fatigue training in decision-making and human capabilities specific to collegiate aviation pilots was necessary.

Researchers distributed the Collegiate Aviation Fatigue Inventory-I (CAFI-I) to collegiate aviation pilots at a Code of Federal Regulations (CFR) Part 141 flight training and four-year degree-awarding university in the Midwestern region of the United States ($n = 122$). Results suggested that fatigue negatively impacted flight training activities. Fifty-one percent of respondents indicated that they had proceeded more than once with flight activities despite being extremely tired. Seventy-eight percent of the participants reported that they had overlooked errors and did not give their best during flights because of fatigue [30].

The negative impact of fatigue goes beyond safety and into the learning process. It is plausible that a well-rested pilot group will learn better and potentially reduce the costs of training by lowering lesson repeats, cancellations, and test failures. The authors recommended adding additional flight programs to increase the number of responses in order to ascertain more robust results.

Understanding the causes, symptoms, and effects of fatigue is an important aspect for training and education, policy, and decision making [5]. The top three solutions were more sleep, reduced workload, and the better scheduling of obligations. A finding of concern was that only half of the respondents indicated that they were fully engaged with proper exercise, desirable eating habits, and effective stress management techniques [17].

In another study, researchers distributed a survey to a Midwestern collegiate aviation program ($n = 138$). Though students reported correct strategies to combat fatigue, results also indicated that students lacked enough quality sleep, had difficulties managing high academic workloads, and were not following regular sleep patterns [20]. Further exploration of survey data provided by collegiate aviation pilots suggested that only 11% ($n = 14$) of the participants considered quality and quantity of sleep a reliable indicator of fatigue levels. A finding of concern was that 43% ($n = 52$) of the respondents indicated that they had not received any type of fatigue identification and training during ground and or flight training activities [19,30].

A study on predictive relationships between factors that underlie fatigue in aviation hypothesized that younger pilots would have higher levels of fatigue due to their enhanced social activities and that females were more prone to higher levels of fatigue due to domestic and socio-economic factors that limit their opportunities to rest. Their hypothesis was based on previous studies which had found predictive relationships in terms of disturbed sleep, high immersion in work, high work demands, social support, being a female, being a supervisor and high age [51,52].

It was interesting that the authors did not observe any significant predictive relationships when examining factors such as age and gender in their study. It is instructive to know that nominally the majority of respondents in the collegiate aviation environment are young people (under 30 years). This makes it a challenge in assessing demographic variations using that variable. Therefore, researchers in this study decided to explore demographic variables that affect perceptions of fatigue in aviation operations, such as gender, academic enrolment levels and flight certification levels [52].

The results of these studies provide similar evidence for the challenges facing collegiate aviation pilots when attempting to identify and mitigate fatigue during flight training. Interestingly, a common finding in all these studies is that there is a need for improved training and education as a mitigation strategy against fatigue during flight training. Training can include topics such as causes of fatigue, fatigue awareness, best practices for obtaining quality sleep, time management, and the benefits of a healthy lifestyle.

2.2. Research Questions and Hypothesis

The research team for the current study distributed the CAFI-II to eight collegiate aviation flight programs in the United States to gain a clearer understanding of fatigue causes, effects, lifestyle choices, and the relationships between those constructs and the over-arching dimension fatigue in collegiate aviation operations. The following research questions were addressed:

1. What is the effectiveness of proposed measurement models of factors underlying the dimension of fatigue in collegiate aviation?
2. What is the strength of relationships between the three underlying factors and the overarching dimension of Fatigue?
3. What are the variations in mean scores of demographic group perceptions of factors that underlie fatigue in collegiate aviation?

As part of research question two, hypotheses outlining the strength of relationships between the factors that explain fatigue in collegiate aviation were assessed. The following hypotheses were validated:

Hypothesis 1 (H1). There exists a relationship between lifestyles that increase fatigue (Lifestyle) and the over-arching construct fatigue (H1: βlifestyle $\neq 0$).

Hypothesis 2 (H2). There exists a relationship between the causes of fatigue (Causes) and the overarching construct of fatigue. (H2: βCauses $\neq 0$).

Hypothesis 3 (H3). There exists a relationship between awareness of fatigue factors (Awareness) and the overarching construct of fatigue. (H3: βAwareness $\neq 0$).

3. Materials and Methods

3.1. Participants

The research team reached out to several collegiate aviation flight program personnel. Eight faculty members at various programs agreed to distribute the survey. All eight universities were in the Midwest and represented small, medium and large flight programs. Additionally, all eight programs are accredited by the Aviation Accreditation Board International and are certified under CFR Part 141. The participants in this study were collegiate aviation pilots including flight instructors. The entire study was in accordance with the Institution Review Board (IRB) guidelines. The researchers sought collegiate aviation pilots, aged 18 years or older, who had previously flown in the last six months, and were currently enrolled in a Part 141 flight training program.

3.2. Research Instrument

In this study, the researchers made minor modifications to the validated 26 CAFI items [25,30]. The CAFI was derived from a modification of a survey instrument published by McDale and Ma [18]. This foundational paper examined similar constructs as the CAFI, but tailored for flight instructors. Exploratory Factor Analysis (Principal Axis Factoring) was used for exploring the underlying structure of items in the CAFI. The reported overall scale reliability in terms of the Cronbach's alpha (α) was good ($\alpha = 0.754$). All the underlying sub-scales had acceptable reliabilities ($\alpha \geq 0.70$).

The three underlying sub-scales are: fatigue awareness (eight items, $\alpha = 0.755$); Causes of fatigue (11 items, $\alpha = 0.747$); lifestyle (seven items, $\alpha = 0.763$). The current revisions included changes to response formats for some demographic variables such as "age" and "approximate total logged flight time". The classification range format was replaced by open ended blank slots to allow respondents to fill in their exact age and flight time. Relevant items for each of the three sub-scales used in this study and sourced from the final version of CAFI-II are provided (see Appendix A).

After IRB approval the survey was distributed to the collegiate aviation programs through email using Qualtrics® software. A link which directs respondent to the anonymous survey was embedded in the email sent out to respondents from their respective flight operations listserv. Three reminders were sent throughout the data collection period. The data collection period was the end of Fall 2019 and the beginning of the Spring 2020 semester.

3.3. Data Analysis

All data collected were anonymous and available for the research team to access. The data were then exported into the IBM AMOS 25® and SPSS 26®. Preliminary data analyses included normality checks using histograms with normality curve and N-N plots. Skewness and Kurtosis values were also checked. Box plots were also used to identify potential outliers in the data set. The descriptive statistics did not show any substantial deviations from normally distributed data. IBM SPSS® 26 analyze function for "pair-wise deletion of missing data" was used for the missing data analysis.

First-order Confirmatory Factors Analysis (CFA) was used to assess the goodness-of-fit of hypothesized measurement models of factors that underlie the dimension of collegiate aviation fatigue. A Structural Equation Model (SEM) in the form of a relational path model was used to test hypotheses postulated about predictive relationships between the factors and the dimension of fatigue. It was also used to determine the strength of relationships between these factors and the dimension of fatigue.

Specifically, the full-information maximum likelihood approach using the IBM AMOS 25® was used for model assessments, strength of relationships between measurement scale items, and the three factors underlying collegiate aviation fatigue. The goodness-of-fit indices Chi-squared (X^2), Normed Fit Index (NFI), Incremental Fit Index (IFI), Comparative Fit Index (CFI) and Root Mean Square Error Approximation (RMSEA) with various acceptance criteria were reported for all measurement models [53,54].

The reliabilities of scale items that loaded strongly in the measurement models were determined and the convergent/discriminant validity of each underlying factor was assessed. Cronbach's alpha was used to confirm the internal consistency of scale items, and the average variance extracted (AVE) method recommended by Fornell and Larcker and Hair et al. [55,56] was used for convergent and divergent validity tests.

After the reliability and validity tests, scale items for each factor were summed to create measured constructs representing these factors for subsequent relational analysis. A fully validated structural model showing the regression weights (β) and Squared Multiple

Correlations (SMC) was proposed. A simple Analysis of Variance (ANOVA) was used to determine variations in means of scale-item scores of the three factors underlying fatigue among various demographical groups, such as flight certificates held, academic levels and gender. Though the CAFI-II has additional survey items, the scope of this paper is limited to assessing the three constructs, along with demographics.

4. Results

4.1. Demographics

Demographic information was collected as part of the survey, including gender, enrolment level, highest certificate held, approximate total logged flight time, and names of institutions. Not all participants responded to the demographic items. Nonetheless, all percentages were rounded to the nearest tenth. About 75% of respondents were male while about 20% were female.

There were 422 responses for the survey item that requested age. It is estimated that there were 1000 total pilots enrolled at the time of survey distribution, which gives a response rate of about 42%. Results indicated that the mean age was close to 21 years old (M = 20.58, Mdn = 20, SD = 2.627). The youngest participant age was 18 years old while the oldest respondent was 40 years old. Many of the participants were Student or Private Pilots and had 200 h or less of flight time. Table 1 details the demographic distribution of the research participants.

Table 1. Summary of Participant's Demographics.

Institution	**(*n*)**	**Percent**
Institution 1	99	23.5%
Institution 2	67	15.9%
Institution 3	56	13.3%
Institution 4	51	12.1%
Institution 5	41	9.7%
Institution 6	36	8.5%
Institution 7	31	7.3%
Institution 8	20	4.7%
Did not to answer	21	5.0%
Total	**422**	**100%**
Gender	**(*n*)**	**Percent**
Female	85	20.1%
Male	318	75.4%
Prefer not to say	19	4.5%
Total	**422**	**100%**
Age	**(*n*)**	**Percent**
18–21	305	72.3%
22–25	66	15.6%
26–29	11	2.6%
30+	23	5.5%
Did not answer	17	4.0%
Total	**422**	**100%**
Enrolment Level	**(*n*)**	**Percent**
Freshmen	74	17.5%
Sophomores	93	22.0%
Juniors	107	25.4%
Seniors	110	26.1%
Graduate	38	9.0%
Total	**422**	**100%**

Table 1. *Cont.*

Highest Certificate Held	**(*n*)**	**Percent**
Student Pilot	106	25.1%
Private Pilot	163	38.6%
Commercial Pilot	57	13.5%
Certified Flight Instructor (CFI/II/ME)/ATP	96	22.5%
Total	**422**	**100%**
Approximate Total Flight Time	**(*n*)**	**Percent**
0–150	207	49.1%
151–300	132	31.3%
301–450	32	7.6%
451–600	9	9.1%
600+	27	6.4%
Did not answer	15	3.6%
Total	**422**	**100%**

4.2. Research Question One

What is the effectiveness of proposed measurement models of factors underlying the dimension of fatigue in collegiate aviation?

A hypothesized three-factor structural model of fatigue in collegiate aviation composed of causes and experiences with fatigue in normal flight activities (Causes), awareness of symptoms of fatigue (Awareness), and lifestyles that reduce the effects of fatigue (Lifestyle) was assessed. The model hypothesizes the relationship between these underlying factors and the over-arching concept of fatigue in a collegiate aviation program.

The initial hypothesized measurement model had eight items for Awareness, seven items for Lifestyle, and 11 items for Causes.

First-order CFA was used to determine the strength of relationships between the items and their factors and among the three factors (correlation/covariances). Finally, the goodness-of-fit of various competing models was assessed and the model with the best fit was proposed. The maximum likelihood estimation (MLE) of the AMOS 25® software was used for the analyses. A bootstrapping sampling technique (5000) and modification indices were used during iterations of the various competing models to determine best fit.

The initial analysis without any constraints imposed on item parameters yielded a model with goodness-of-fit indices as follows: $\chi 2$ (299, n = 422) = 1466.465; CMIN/DF = 4.905, p = 0.000; NFI = 0.681; IFI = 0.728; TLI = 0.703; CFI = 0.727; RMSEA = 0.096 (0.091–0.101). Based on the modification indices and theoretical considerations, alternate models were explored, which produced seven competing models with various fit indices. Model VII, which had the most acceptable fit index per recommendation, was selected for proposal as the full structural model (Figure 1) [54,57]. Details of the fit indices are shown in Appendix B.

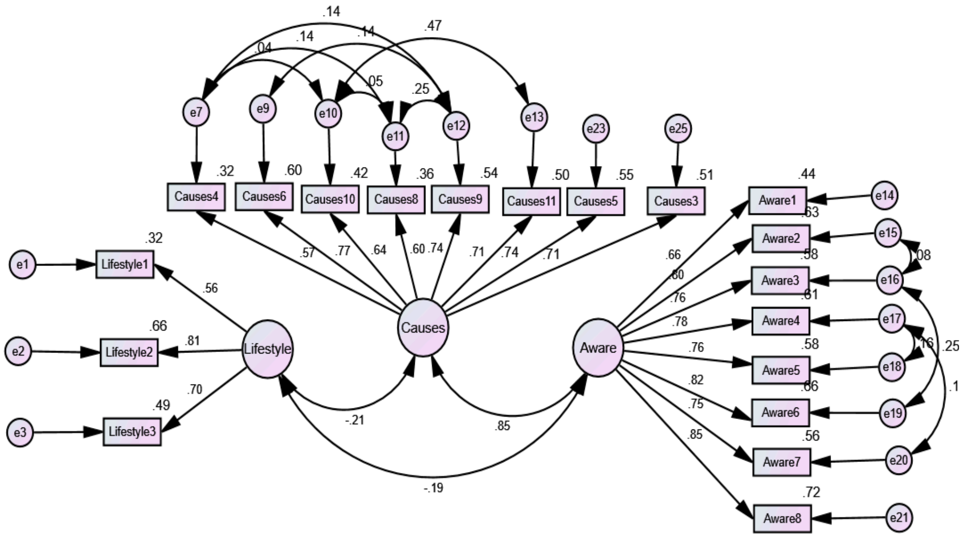

Figure 1. A Three-Factor Structural Model for Collegiate Aviation Fatigue (Model VIII). (.xx means 0.xx).

4.3. Research Question Two

What is the strength of relationships between the three underlying factors and the over-arching dimension Fatigue?

To validate the hypotheses outlining the strengths of relationship between the three underlying factors and the dimension fatigue in collegiate aviation (Fatigue), the convergent/discriminant validity and reliability of items that were retained for each factor in the structural model (Figure 1) were assessed. This was done due to modifications to CAFI scale items.

The extant Literature suggests that a Cronbach's alpha value of 0.7 or higher indicates good reliability of measured items [55]. In addition, a composite reliability (CR) of 0.7 or higher suggests good reliability and indicates internal consistency exists. It also means that all measures consistently represent the same latent construct [56].

Factor loadings and average variance extracted (AVE) methods were used to assess the convergent validity. A comparative approach was adopted in determining evidence of discriminant validity. The initial analysis compared the square root of the AVE value of any construct with the correlation estimate between that construct and others [55,56].

The square root of AVE value should be greater than the correlation estimates to provide good evidence of discriminant validity and the value of AVE for each construct should be at least 0.50. Results suggested that almost all the factors had good reliability and internal consistency. Table A2 shows evidence of construct validity since all the AVE values were above 0.05. The squared root of the AVE values of all factors were greater than the correlation estimates and provided good evidence of discriminant validity.

The measured construct for the three factors were derived by summing the retained items in each factor from Figure 1. The new measured constructs were used to validate the hypotheses outlining the strengths of the relationship between the three measured constructs and the dimension of fatigue in collegiate aviation (Fatigue). A hypothesized measurement model is outlined in Figure 2 to show the strength of relationships between the three underlying factors and the overarching dimension of Fatigue.

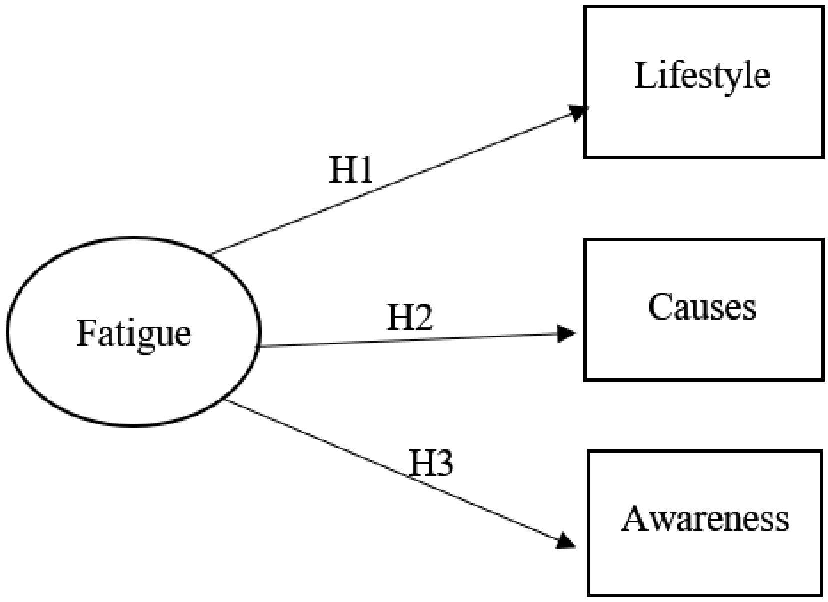

Figure 2. Hypothesized Measurement Model of Fatigue in Collegiate Aviation.

The results in Figure 3 show that perceptions of respondents of symptoms that cause fatigue had the highest standardized regression weight (β = 0.93, $p < 0.001$) and predictive relationship with fatigue. The result suggests that, due to the direct (unmediated) effect of over-arching dimension symptoms of fatigue, when fatigue among collegiate aviation students goes up by 1 standard deviation, their perceptions of symptoms that cause fatigue increased by 0.93 standard deviations. The SMC value of 0.87 suggests that the predictors of symptoms that cause fatigue explained about 86% of its variance and shows a high effect size.

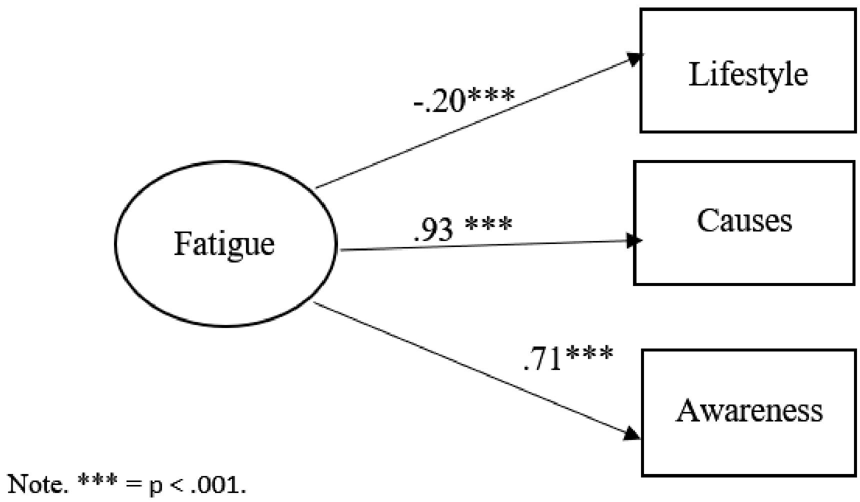

Figure 3. Final Measurement Model showing Strength of Relationships between the Three underlying factors and the over-arching dimension Fatigue. (.xx means 0.xx).

On the contrary, perceptions of lifestyles that reduce fatigue were the factor with the lowest standardized regression weight (β = −0.20, $p < 0.001$) and showed that, as fatigue among collegiate aviation students goes up by a unit standard deviation, lifestyles that reduce fatigue go down by 0.20. The SMC value of 0.04 suggest a rather weak effect size. Fatigue Awareness which describes the overall experience of respondents related to fatigue during all flight activities had a standardized regression weight (β = 0.71, $p < 0.001$).

These results suggested that, due to the direct (unmediated) effect of fatigue on experience and awareness, when fatigue among collegiate aviation students goes up by 1 standard deviation, their experience of fatigue increases by 0.71 standard deviations. This is in addition to any indirect (mediated) effect that fatigue may have on fatigue awareness. The results also suggested an acceptable fit of the model to the data based on all the goodness-of-fit indices thresholds (χ^2 (1, n = 422) = 3.335; p = 0.068; CMIN/DF = 3.335; NFI = 0.987; RFI = 0.960; IFI = 0.991; TLI = 0.972; CFI = 0.991; RMSEA = 0.064 (0.000–0.169)) [57–59]. The results suggest that all the alternate hypotheses postulated can be accepted as compared to the null. Appendix B shows standardized regression weights for all constructs and their *p*-values for testing the hypotheses. Figure 4 shows a conceptual model that highlights relationships between items and their various factors, and between the factors and the over-arching dimension Fatigue.

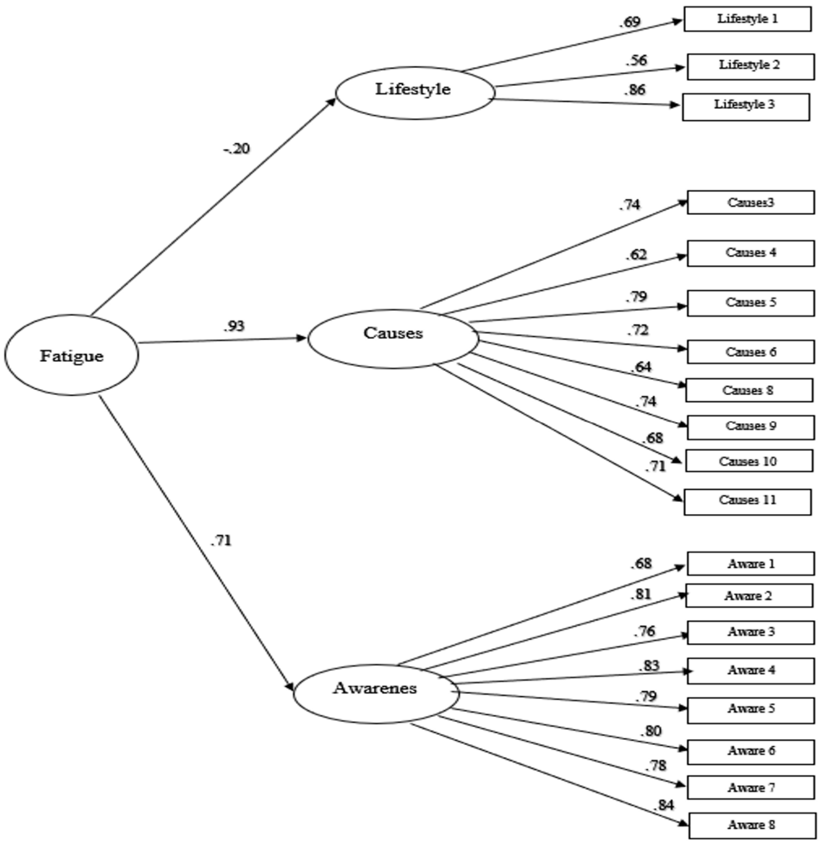

Figure 4. Full Conceptual Model of Fatigue Highlighting Strength of Relationships (Covariances Omitted for Clarity). (.xx means 0.xx).

4.4. Research Question Three

What are the variations in mean scores of demographic group perceptions of factors that underlie fatigue in collegiate aviation?

4.4.1. Academic Enrolment Status

An objective of this study was to find out if there was a significant difference between the mean scores of responses to items in the measured constructs/factors; Lifestyle, Causes and Awareness of Fatigue among academic enrolment status (freshmen, sophomores, juniors, and seniors). A one-way ANOVA was conducted, and the results showed that there were no significant differences in fatigue lifestyle responses by academic enrolment status, F (4, 421) = 0.083, p = 0.988 (ns). There were significant differences in causes of fatigue, F (4, 421) = 2.92, p = 0.021 and awareness of fatigue, F (4, 421) = 6.73, p = 0.000.

A post-hoc analysis using Bonferroni corrections of the causes of fatigue showed that there were significant differences between the mean responses of freshmen (M = 2.52, SE = 0.099) and seniors (M = 2.85, SE = 0.074) with a 95% confidence interval (CI) (0.0140–0.6638). Another post-hoc analysis of the awareness and experiences of other fatigue variable showed that there were significant differences between freshmen (M = 1.80, SE = 0.085) and sophomores (M = 2.13, SE = 0.060) with 95% CI (0.0441–0.6204); freshmen (M = 1.80, SE = 0.085) and juniors (M = 2.15, SE = 0.053) with 95% CI (0.0691–0.6268); and freshmen (M = 1.80, SE = 0.085) and seniors (M = 2.28, SE = 0.062) with 95% CI (0.1991–0.7557). The results suggested a relative increase in magnitude of the experience fatigue with higher academic enrolment levels.

4.4.2. Flight Certificate

A one-way ANOVA was conducted, and the results suggested significant differences in the mean responses by flight certificate held for all the three measurement variables, fatigue lifestyle, F (3,419) = 4.813, p = 0.003, causes of fatigue, F (3,419) = 4.284, p = 0.005, and awareness of fatigue, F (3,419) = 11.698, p = 0.000. A post-hoc analysis using Bonferroni corrections of fatigue lifestyle showed that there were significant differences between the mean responses of participants with CFI certificates (M = 3.31, SE = 0.085) and those with commercial pilot certificate (M = 3.74, SE = 0.088) with 95% CI (0.091–0.789).

The post-hoc analysis of fatigue lifestyle showed a significant difference between mean responses of participants with student pilot certification (M = 3.40, SE = 0.073) and commercial (M = 3.74, SE = 0.088), with 95% CI (0.007–0.684). There were also significant differences in mean responses between participants with commercial certificate (M = 3.74, SE = 0.088) and those with private pilot certificate (M = 3.38, SE = 0.053), with 95% CI (0.071–0.644). In the case of causes of fatigue, there were significant differences between the mean responses of participants with student pilot certification (M = 2.54, SE = 0.079) and CFI certificate (M = 2.88, SE = 0.070) with 95% CI (0.066–0.666).

A final post-hoc analysis of the awareness of the fatigue variable suggested a significant difference in the mean responses of participants with student pilot certification (M = 1.83, SE = 0.068) and private pilot certification (M = 2.18, SE = 0.044), with 95% CI (0.142–0.583). There was also a significant difference in the mean responses of participants with student pilot certification (M = 1.83, SE = 0.068) and commercial pilot certification (M = 2.19, SE = 0.089) with 95% CI (0.088–0.666). A final post-hoc suggested significant difference in the mean responses of participants with student pilot certification (M = 1.83, SE = 0.068) and CFI certificates (M =2.30, SE = 0.062), with 95% CI (0.228–0.738).

4.4.3. Gender

An independent *t*-test, which is an inferential statistical test that determines whether there is a statistically significant difference between the means in two unrelated groups, was used for the analysis (Fields, 2009). The data were assumed normal and the assumption of homogeneity of variance was assessed by the Levene's test, with an F-ratio of F (420) = 5.34, p = 0.021 (2T) for fatigue lifestyle; F (420) = 3.03, p = 0.082 (2T) for causes of fatigue; F (420) = 1.32, p = 0.251 (2T) for awareness of fatigue.

The result indicated that the assumptions of equal variance were met for the variables causes of fatigue and awareness of fatigue; therefore, the equal variances assumed that a version of the t- test was used. There were no significant differences in the models.

5. Discussion and Conclusions

The overall purpose of this study was to understand fatigue as a multi-factorial dimension in the collegiate aviation operational environment and to assess potential relationships among these factors using hypothesized measurement models. The results validated the initial assertion that fatigue, as a multi-factorial dimensional construct, had three explanatory constructs (causes of fatigue, reported fatigue symptoms, and lifestyle choices among collegiate aviation pilots) [25,30].

Secondarily, the reliability and construct validity of the CAFI-II was further assessed and the reliabilities for the entire scale were consistent with findings in earlier studies [17,30]. The study provided evidence of construct validity in terms of convergent and discriminant validities for the CAFI-II, which further strengthened the psychometric capabilities of the instrument for use in assessments of fatigue in collegiate aviation operations.

Another objective of the study was to assess the strength of relationships between the three measured constructs (Causes of fatigue, Awareness of fatigue, and Lifestyle choices among collegiate aviation pilots) and the overarching dimension of fatigue in collegiate aviation operations. The results suggested a direct and strong predictive relationship between fatigue in collegiate flight training and the perceptions of respondents of conditions that cause fatigue and fatigue awareness.

Findings from analyzing the relationships between scale items and their constructs in the best-fit model of fatigue suggested that respondents who had a favorable perception of fatigue risk and management in collegiate aviation programs had a better understanding of the causes of fatigue. This is very important in collegiate aviation fatigue risk management educational efforts. It further consolidates earlier research recommendations for a scientific and evidence-based approach to highlight the symptoms and causes of fatigue.

It was interesting to observe from the final measurement model that, as fatigue-reducing lifestyles minimized, respondents perceived heightened fatigue in their activities. This finding is very instructive and suggests that collegiate aviation programs must enhance continuous education for pilots and other supporting personnel in fatigue identification and management strategies. Moreover, such programs should track pilots' flight and duty times using evidence-based approaches [5,26,27].

The results suggest that effective strategies for predictive fatigue risk identification and mitigations can include keeping track of flight student's workload (other than flight and duty time) and promoting the use of confidential safety reporting systems regarding fatigue-related issues, as recommended in previous studies [5,17]. Proactivity on the part of collegiate operational safety management teams to provide expedited feedback on fatigue-related issues reported by pilots could create better awareness of fatigue, while informing personnel about the symptoms and causes of fatigue.

In terms of encouraging desired safety attitudes and enhanced fatigue-reducing lifestyles, peer to peer advocacy and empowered accountability may help to reduce risky behaviors such as flying while fatigued and non-adherence to quality sleep schedules among flight students [23]. Flight students can act as advocates for lifestyles that reduce fatigue in flight operations while having a role in how policies and procedures related to fatigue management are developed and implemented in the organization. Aviation students' associations can be very helpful in such advocacy at the grass-roots level.

Respondents with CFI certificates had a relatively lower mean score on items that indicated fatigue-reducing lifestyle choices when compared to commercial pilot holders. This may be due to the notion that CFIs have a higher workload and tasking requirements which make them more vulnerable to the effects of fatigue. Some CFIs also balance responsibilities as student employees within their collegiate flight programs and the requirements of a higher-level college academic load which predisposes them to a high risk of fatigue. These CFIs may also have domestic and marital responsibilities, making them more vulnerable to lifestyles that predispose them to excessive fatigue.

The perceptions of increased levels of fatigue among such upper-level students can also be explained by the notion that most of these students are 21 years old and above, which provides opportunities for unrestricted socializing in bars and night clubs, which can enhance fatigue risk factors. An emphasis by collegiate aviation program managers on fatigue risk management training embedded in advanced level academic courses such as crew resource management (CRM), human factors and safety management systems (SMS) that are normally part of CFI initial and recurrent training, will be expedient.

The results also suggested that student pilots were the group of certificate holders with minimal awareness of the effects of fatigue and how to manage it as compared to CFIs and other certificate holders. It behooves collegiate aviation program managers to develop fatigue risk management syllabi or mesh this into introductory aviation safety courses, such as those on human factors and crew resource management, to provide the fundamentals of fatigue awareness and coping strategies. There were no significant differences in the mean scores of perceptions on fatigue by gender. This finding corroborates observations by other researchers, who also suggested that gender and age were not predictive of perceptions related to fatigue [51].

Some limitations of the study were the narrow band of age, which does not make the results generic to other aviation professionals outside that domain. It must also be noted that these were opinions of respondents that could have been influenced by psychosocial factors such as stress, family issues, and political upturns. The data fortunately were collected prior to the outbreak of the COVID-19 global pandemic and this may have minimized potential biases in sampling responses due to its adverse social, medical, and academic impact on collegiate students worldwide.

Approximately 93% of the respondents had up to 600 flight hours. Additionally, only 23% were CFIs. The research team attempted to collect data from collegiate aviation pilots with different flight experiences and certificates in order to have a better picture of the fatigue issue afflicting those aviators. The stated limitations could potentially bias some of the findings in this study and affect generalizability across the entire aviation workspace.

This study has implications for future studies, and it is highly recommended that a replication be carried out using a broader and diverse sample drawn from international universities with collegiate aviation programs. It may also be insightful to assess the impact of external factors such as significant global events (e.g., COVID-19) and national cultural dimensions on the relationships between the underlying constructs and over-arching dimension of collegiate aviation fatigue.

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Institutional Review Board Statement: The study was conducted in accordance with the Purdue University Human Research Protection Program System, and the protocol was approved by the Ethics Committee (protocol code IRB-2019-189 and 20 November 2019).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study before they began the survey questionnaire.

Data Availability Statement: The data are not publicly available due to Institution Review Board limitations. The data can only be handled by approved key personnel and investigators.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Collegiate Aviation Fatigue Inventory-II (CAFI-II)

Demographics

- Age:
- Gender:
- Enrolment status:
- Highest Certificate Held:
- Approximate total logged flight time:
- Institution

Fatigue Awareness

Please rank the accuracy of the statement describing your overall experience during all of your flight activities.

	Never	Rarely	Sometimes	Often	Always
I have struggled to stay awake during a flight.					
I have remarked (out loud or to myself) about how tired I was but proceeded with the flight anyway.					
I have overlooked mistakes during a flight because of reduced judgment caused by fatigue.					
I have felt disinterest during flight activities because I was fatigued.					
I have not given my best effort due to fatigue.					
I have made mistakes during flight activities because I was fatigued.					
I have felt heightened irritation during a flight because I was fatigued.					
My abilities to carry out tasks requiring concentration have been decreased due to fatigue.					

What symptoms cause you to realize you are fatigued?
Causes of Fatigue

Please rank the accuracy of each statement describing contributing factors which may have led to fatigue during flight activities.

	Never	Rarely	Sometimes	Often	Always
Flying during night (sunset through sunrise).					
Flying a long cross-country (2.5 h or over).					
Working a long day.					
Stress caused by family or other psychological conditions.					
Poor scheduling of flight lessons (e.g., too early, too late, or too many).					
Poor scheduling of academic classes.					
Lack health or fitness.					
Personal activities or other commitments (e.g., 2nd job).					
Academic activities (e.g., midterms, student organizations, etc.).					
Quality of sleep (restlessness or interrupted sleep).					
Not of enough sleep.					

Please comment on other factors that contributed to fatigue:
Lifestyle

Given each item, please select the accuracy of the statement describing your current lifestyle.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I have a healthy academic and life balance.					
I regularly exercise.					
I maintain a healthy diet.					
I am good at workload management.					
I am good at stress management.					
I get adequate sleep every night (quantity and quality).					
I prepare well to get adequate sleep (i.e., limit electronic device use, caffeine, disruptions, noise, etc.)					

In your experience what are the most significant factors that inhibit your quality/quantity of sleep?

Personal Solutions

Please read through the entire list then rank (click and drag) in order the following personal solutions to mitigate fatigue, 1 being the most important and 10 being the least important. You can provide factors that are not listed in the comment box below.

- Reduced workload
- Scheduled breaks
- More sleep
- Efficiency in scheduling of classes and flight activities
- Management of sleep preparation
- Self-awareness of fitness to fly
- Guaranteed rest for a given amount of flying time
- Physical exercise
- Healthy eating habits
- Better management of non-work issues

What other personal solution(s) do you find important?

Based on your overall experience during all of your flight activities.

	Never	Rarely	Sometimes	Often	Always
Fatigue impacts my flight activities.					

How many hours do you typically work per week Monday-Friday? (include studying, working, student organizations, etc.) (e.g., 1, 2, 3).

How many hours do you typically work per weekend Saturday-Sunday? (include studying, working, student organizations, etc.) (e.g., 1, 2, 3).

How many hours do you typically socialize per week Monday-Friday? (e.g., 1, 2, 3)

How many hours do you typically socialize per weekend Saturday-Sunday? (e.g., 1, 2, 3).

Have you ever received fatigue training during your academic or flight training course work? Yes or No.

What specific method do you use to ensure you are fit to fly?

Please identify in general your fatigue level during the specified time periods. We may be able to understand your preference for morning or evening.

	Fully alert	Very lively but not at peak	Ok, somewhat fresh	A little tired, less than fresh	Moderately tired, let down	Extremely tired, very difficult to concentrate	Completely exhausted, unable to function effectively
Early morning (6am–9am)							
Morning (9am–noon)							
Early afternoon (noon–3pm)							
Afternoon/early evening (3pm–6pm)							
Evening (6pm–9pm)							
Night (9pm–6am)							

Please provide any comments that would help improve the survey (unclear items, length of survey, areas that were not addressed, etc.) Thank you for your feedback and participation.

Appendix B.

Table A1. Goodness-of-Fit Indices for Fatigue.

Iteration	**Chi Square (χ^2)**	**NFI**	**IFI**	**TLI**	**CFI**	**RMSEA**
Model 1	χ^2 (299, n = 422) = 1466.465; CMIN/DF = 4.905, p = 0.000	0.681	0.728	0.703	0.727	0.096 (0.091–0.101)
Model II	χ^2 (290, n = 422) = 1115.220, p = 0.000, CMIN/DF = 3.846	0.757	0.808	0.783	0.807	0.082 (0.077–0.087)
Model III	χ^2 (287, n =422) = 1002.132, p = 0.000 CMIN/DF = 3.492	0.782	0.834	0.810	0.833	0.077 (0.072–0.082)
Model IV	χ^2 (138, n = 422) = 431.237; CMIN/DF = 3.125, p = 0.000	0.836	0.882	0.834	0.880	0.071 (0.064–0.079)
Model V	χ^2 (143, n =422) = 360.470, p = 0.000 CMIN/DF = 2.521	0.890	0.930	0.916	0.930	0.060 (0.052–0.068)
Model VI	χ^2 (141, n =422) = 350.112, p = 0.000 CMIN/DF = 2.483	0.893	0.933	0.915	0.932	0.059 (0.052–0.069)
Model VII	χ^2 (141, n =422) = 322.316, p = 0.000 CMIN/DF = 2.286	0.887	0.933	0.908	0.932	0.055 (0.047–0.063)
Model VIII	χ^2 (141, n = 373) = 281.668; p = 0.000 CMIN/DF = 2.086	0.893	0.941	0.918	0.940	0.051 (0.042–0.067)

Table A2. Reliability and Convergent Validity Assessment.

Construct/Factor	**Cronbach's Alpha**	**Composite Reliability (CR)**	**Average Variance Extracted (AVE)**	**Square Root of AVE**
Lifestyle (3 items)	0.701	0.698	0.51	0.71
Causes (8 Items)	0.846	0.843	0.50	0.70
Awareness (8 Items)	0.880	0.878	0.60	0.77

Table A3. Discriminant Validity Assessment using the Fornell-Larcker Method.

	Lifestyle	Causes	Awareness
Lifestyle	**0.71**		
Causes	−0.23 **	**0.70**	
Awareness	−0.21 **	0.66 **	**0.77**

Note. Correlation is significant at the 0.01 level (2-tailed).

Table A4. Test of Hypotheses.

Hypotheses	Standardized Weight (β)	Squared Multiple Correlations (R^2)	Hypotheses
H1	−0.20 ***	0.04	Accept
H2	0.93 ***	0.87	Accept
H3	0.71 ***	0.50	Accept

Note: *** $p < 0.001$.

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