Aircrew Fatigue Perceptions, Fatigue Mitigation Strategies, and Circadian Typology

Megan B. Morris; Jennifer P. Howland; Kelly M. Amaddio; Glenn Gunzelmann

BACKGROUND: Human fatigue is an important factor within aviation, leading organizations to develop strategies to assess and mitigate associated risks. The U.S. Air Force's Air Mobility Command (AMC) conducted the current pilot study to assess fatigue-related risks and issues in mobility operations. Specifically, we examined the relationship among fatigue perceptions, fatigue mitigation strategies, performance effectiveness graph reference, and circadian typology.

METHODS: There were 21 volunteers from the Joint Base Charleston C-17 pilot community ($M_{age} = 28.67$; $SD_{age} = 2.11$; $Proportion_{male} = 85.71\%$) who completed a survey. Items referred to fatigue perceptions, fatigue mitigation strategies, performance effectiveness graph reference, and circadian typology. We examined descriptive statistics, correlations among the variables of interest, and possible moderation effects of circadian typology.

RESULTS: Overall, aircrew perceived fatigue to be a serious safety of flight concern. Personal fatigue concerns and perceptions of pressure to continue missions despite fatigue were associated with increased use of the strategy of limiting light exposure during sleep episodes ($r = 0.49$ and 0.47). Fatigue perceptions were not directly associated with performance effectiveness graph usage. Results suggested that morning type participants might be more likely to utilize specific fatigue mitigation strategies when there are concerns of fatigue compared to evening types.

DISCUSSION: Despite organizational efforts, fatigue continues to be a serious concern for the mobility community. This pilot study suggests that circadian typology might affect the relationship between fatigue perceptions and fatigue mitigation strategies and resource use. Future research should further examine these relationships and their impact within fatigue risk management (FRM) programs.

KEYWORDS: fatigue perceptions, fatigue mitigation strategies, circadian typology, aviation.

Morris MB, Howland JP, Amaddio KM, Gunzelmann G. *Aircrew fatigue perceptions, fatigue mitigation strategies, and circadian typology*. Aerosp Med Hum Perform. 2020; 91(4):363–368.

Human fatigue is an important factor in aviation, contributing to an estimated 4 to 8% of aircraft accidents.[1] Not only does fatigue result in severe acute consequences such as aircraft operation deviations,[1,9] but it can also result in cumulative effects such as burnout and other negative health effects.[4] As a result, several aviation organizations have implemented policies, guidelines, and fatigue risk management (FRM) programs to combat aircrew fatigue.[3,5] Fatigue is especially a concern in the air mobility community where aircrew commonly have long duty days and missions typically last many days while crossing multiple time zones. Because of the unique demands of military mobility operations, special consideration is needed to assess factors that might affect aircrew fatigue and fatigue mitigation behaviors.

Research suggests that individual differences, such as circadian typology, could affect how aircrew experience fatigue.[8] Circadian typology refers to individual differences in circadian rhythms or sleep/wake cycles. Circadian typology is commonly categorized into morningness and eveningness, but can be further categorized on the continuum.[7] Individuals who exhibit morningness tend to rise earlier and go to bed earlier, whereas individuals who have an eveningness typology tend to rise later and go to bed later. There is little research examining the effects of circadian typology on fatigue within aviation.[6,13,16] Prior research suggests that circadian typology is related to self-reported fatigue, such that morning-type individuals might be

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This manuscript was received for review in April 2019. It was accepted for publication in December 2019.

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DOI: https://doi.org/10.3357/AMHP.5396.2020

more susceptible to fatigue when time zone changes and shiftwork like schedules are present.[6,13] Thus, it is possible that individuals higher in morningess in the air mobility community might be more likely to self-report fatigue. In addition to examining how circadian typology affects experiences of aircrew fatigue, it is also important to examine how circadian typology affects aircrew fatigue mitigation behaviors. Circadian typology might have a direct relationship with these behaviors, or act as a moderator in terms of the relationships between fatigue-related perceptions and fatigue mitigation behavior. To current knowledge, these relationships have not been explored in research.

In the current pilot study, we examine the associations among circadian typology, fatigue perceptions (including self-reported fatigue and general fatigue perceptions about the air mobility community), and fatigue mitigation behavior. We also conduct an exploratory analysis to examine potential moderating effects of circadian typology with these fatigue-related perceptions and behaviors. We specifically examine these relationships in the context of the U.S. Air Force Air Mobility Command (AMC) community and discuss the implications of these relationships in terms of AMC's larger fatigue risk management structure, which is housed in their Aviation Operational Risk Management (AvORM) program.

METHODS

Subjects

Volunteers were recruited from the C-17 pilot community stationed at Joint Base Charleston. Initially, 22 pilots participated in the pilot study ($M_{age} = 28.59$; $Mdn_{age} = 29$; $SD_{age} = 2.09$; $Proportion_{male} = 86.36\%$). The study consisted of aircrew pilots completing an initial questionnaire, daily logs, and Psychomotor Vigilance Test sessions, and wearing an actigraph watch during missions. In the current paper, we present the results of a portion of the study, the initial questionnaire. One participant did not complete the questionnaire and their data was dropped from the pilot study, resulting in 21 participants ($M_{age} = 28.67$; $Mdn_{age} = 29$; $SD_{age} = 2.11$; $Proportion_{male} = 85.71\%$). Participants had a mean of 1106.67 flight hours (Mdn = 900; SD = 678.51) and included aircraft commanders, instructor pilots, copilots, and evaluator pilots. A majority of volunteers were married (66.67%) and a majority did not have children (66.67%). All volunteers consumed alcohol and caffeine. Only 9.52% used tobacco and 14.29% used sleeping aids. This pilot study was approved by the Air Force Research Laboratory (AFRL) Institutional Review Board under the common rule (32 CFR 219), DoDD 3216.2, and AFI 40-402, protocol number: FWR20160111H.

Materials

The first portion of the questionnaire consisted of demographic items such as position, total flight hours, age, gender, marital status, and whether participants had children. Items also pertained to caffeine, alcohol, tobacco, and sleeping aid usage. Items regarding controlled stimulants were not included as these stimulants are not authorized for use in AMC mobility operations.

Participants indicated how often they used each of five fatigue mitigation strategies with Never, Sometimes, Half of the time, Most of the time, and Always. The strategy items were "Limit light exposure (i.e., eye masks/black out curtains to aid daytime sleeping)," "Align sleep patterns to new location (i.e., staying awake 36+ h to sleep when it's dark at the new location)," "Exercise," "Monitor/change your diet," and "Take in-flight naps." These variables are referenced as Light, Pattern, Exercise, Diet, and Naps in the study tables, respectively.

Participants completed five fatigue-related items concerning general fatigue perceptions regarding the community and self-reported fatigue experiences. Items were rated on a 5-point scale with 1 being Strongly Agree and 5 being Strongly Disagree. Items included "Fatigue is a serious safety of flight concern for the air mobility community," "I have personally felt concerned about my fatigue level with respect to safety of flight," "AMC leadership appears to think fatigue is a serious concern," "I have personally felt pressure to continue a mission despite being overly fatigued," and "Changes need to be made to address pilot fatigue." Items were reversed scored for analyses. These variables are referenced as Community, Personal, Leaders, Pressure, and Changes in the study tables, respectively.

In addition to the preceding fatigue mitigation behavior items, participants were also asked "How often do you reference the AvORM effectiveness graphs prior to a mission?" and answered with Never, Sometimes, Half of the Time, Most of the Time, or Every Time. The effectiveness graph is a fatigue mitigation tool derived from a biomathematical fatigue model and scheduling tool that is available in AvORM. The tool provides aircrew members with predicted performance levels throughout the mission based on the mission schedule, circadian factors, time changes, and associated sleep and nap times. The graph is available to aircrew before a mission and updated versions based on mission changes are accessible through an authorized computer with an Internet connection if available during the mission. This variable is referred to as AvORM in the study tables.

Circadian typology was assessed with the Morningness-Eveningness Questionnaire—Self-Assessment Version (MEQ-SA).[15] The questionnaire includes 19 items with 4 to 5 answer options identified with values ranging from 0 to 6. An example item is "If you usually have to get up at a specific time in the morning, how much do you depend on an alarm clock?" with options and values [4] Not at all, [3] Slightly, [2] Somewhat, and [1] Very much. Scores were calculated by taking the sum of the items. Lower scores represented eveningness, whereas higher scores represented morningness (possible range: 17–86). Cronbach's Alpha was 0.77. Scores are traditionally categorized into one of five (definite evening, moderate evening, intermediate, moderate morning, definite morning)[15] or six (distinguishing between intermediate evening and intermediate morning types)[11] groups representing different circadian typologies. However, some researchers have suggested using the raw sums of the items as the morningness-eveningness dimension can be viewed as a continuum, which also allows for further distinctions within the circadian typology.[11] In the current study we adopt the latter approach. This variable is referred to as MEQ in the study tables. We believe one participant unintentionally missed the last MEQ item, so we chose to use a simple imputation method based on z-scores to derive a score for that particular item.

Procedure

Participants were briefed on the overall study in a group setting and then completed an informed consent document. The participants then completed the initial questionnaire in a group setting and received additional materials for the larger study. The questionnaire consisted of demographic questions, followed by fatigue mitigation strategy items, fatigue perception items, the AvORM reference item, and lastly, the circadian typology items.

Statistical Analysis

Statistical analyses included conducting Spearman's rank correlation tests among the variables of interest with the pspearman package[14] in R (version 3.3.1; R Core Team, Vienna, Austria). To further examine possible moderating effects of circadian typology on the relationship between fatigue perceptions and the use of fatigue mitigation strategies and other resources, we conducted multiple regression analyses. Given the ordinal nature of our outcome variables and fatigue perceptions, ordinal logistic regression is most appropriate. However, given our small sample size we were not able to use ordinal logistic regression. Instead, we opted to examine these relationships with multiple regression using the pequod package.[10] This involved creating a model with main effects of the predictors of interest and their interaction term. The predictors were centered, a common procedure in moderation analyses. An omnibus F test, which compares the moderation regression model to a baseline model with no predictors, is reported. Based on an alpha level of 0.05, models that are significantly better fits or trending as better fits compared to the baseline model are further examined with simple slope tests and plots.

RESULTS

Descriptive statistics for fatigue mitigation strategies, fatigue perceptions, AvORM usage, and circadian typology can be found in **Table I**. Overall, aircrew perceived fatigue to be a serious safety of flight concern for the air mobility community. A majority of participants had personal concerns regarding fatigue. Aircrew tended to perceive that AMC leadership views fatigue as a serious concern and a majority believed that changes are needed to address pilot fatigue. Aircrew members used the fatigue mitigation strategies to various extents. Limiting light exposure was the least endorsed strategy, whereas exercise was the most frequently used strategy. A majority of aircrew responded with "sometimes" in regard to referencing the AvORM effectiveness graph, suggesting that aircrew seldom use the graph and its corresponding fatigue information to develop mitigation strategies. Participants tended to be intermediate evening, intermediate morning, or moderate morning (Range: 39–66) (see Table I for distribution).

Spearman correlations suggested several significant ($P < 0.05$) and approaching significant ($P < 0.10$) relationships among variables (see **Table II**). In terms of the main variables of interest, perceptions of fatigue as a serious safety of flight concern had a large significant positive association with personal concerns of fatigue and the perception that changes are needed to address pilot fatigue. Both personal concerns of fatigue and personally being felt pressured to continue a mission despite being overly fatigued had large significant positive associations with the perception that changes are needed to address pilot fatigue and the use of limiting light exposure as a fatigue mitigation strategy. Although aircrew tended to perceive AMC leadership as viewing fatigue as a serious concern, these perceptions

Table I. Descriptive Statistics for Variables of Interest.

	MEAN	SD	MEDIAN	STRONGLY DISAGREE	DISAGREE	NEITHER DISAGREE OR AGREE	AGREE	STRONGLY AGREE	
Community	4.43	1.03	5.00	4.76%	0.00%	9.52%	19.05%	66.67%	
Personal	3.91	1.22	4.00	4.76%	14.29%	4.76%	38.10%	38.10%	
Leaders	3.33	0.86	3.00	0.00%	14.29%	47.62%	28.57%	9.52%	
Pressure	3.38	1.07	3.00	0.00%	23.81%	33.33%	23.81%	19.05%	
Changes	4.38	0.74	5.00	0.00%	0.00%	14.29%	33.33%	52.38%	
				NEVER	**SOMETIMES**	**HALF OF THE TIME**	**MOST OF THE TIME**	**ALWAYS**	
Light	2.14	1.20	2.00	33.33%	42.86%	4.76%	14.29%	4.76%	
Pattern	2.24	1.04	2.00	19.05%	57.14%	9.52%	9.52%	4.76%	
Exercise	3.33	0.73	3.00	0.00%	14.29%	38.10%	47.62%	0.00%	
Diet	2.91	1.04	3.00	0.00%	47.62%	23.81%	19.05%	9.52%	
Naps	2.91	0.83	3.00	0.00%	38.10%	33.33%	28.57%	0.00%	
				NEVER	**SOMETIMES**	**HALF OF THE TIME**	**MOST OF THE TIME**	**EVERY TIME**	
AvORM	2.67	1.32	2.00	14.29%	47.62%	9.05%	14.29%	14.29%	
				DEFINITE EVENING	**MODERATE EVENING**	**INTERMEDIATE EVENING**	**INTERMEDIATE MORNING**	**MODERATE MORNING**	**DEFINITE MORNING**
MEQ	53.85	8.13	54.50	0.00%	4.76%	28.57%	33.33%	33.33%	0.00%

Fatigue items are reversed scored from original presentation. Note that percentages might not sum exactly to 100% due to rounding.

Table II. Spearman Correlations Among Variables of Interest.

	1	2	3	4	5	6	7	8	9	10	11	12
1. Community	—											
2. Personal	0.67**	—										
3. Leaders	0.17	0.05	—									
4. Pressure	0.20	0.38†	−0.25	—								
5. Changes	0.55*	0.57**	−0.02	0.60**	—							
6. Light	0.38†	0.49*	−0.01	0.47*	0.40†	—						
7. Pattern	0.10	0.29	−0.02	0.03	0.09	0.37†	—					
8. Exercise	−0.01	0.13	0.05	0.31	0.29	0.27	0.08	—				
9. Diet	−0.00	0.23	0.03	0.04	0.32	−0.31	0.00	0.19	—			
10. Naps	0.04	−0.13	0.03	−0.13	0.08	−0.41†	−0.09	−0.05	0.34	—		
11. AvORM	0.23	0.20	0.15	−0.15	0.14	0.01	−0.15	−0.05	0.11	0.08	—	
12. MEQ	0.10	0.41†	−0.21	−0.14	−0.03	0.22	0.19	−0.13	0.12	−0.32	−0.07	—

† $P < 0.10$, * $P < 0.05$, ** $P < 0.01$.

were unrelated to other fatigue perceptions. Interestingly, none of the fatigue perceptions were related to AvORM performance effectiveness graph usage. Personal fatigue concerns were marginally positively related to MEQ scores, suggesting that individuals higher in morningness might be more likely to experience fatigue.

In regard to examining possible moderating effects of circadian typology, only one moderation regression model was found to have a significantly better fit than the baseline model (See **Table III**). This model suggested a significant interaction between circadian typology and the perception that changes are needed to address pilot fatigue on limiting light exposure. Simple slope tests suggested a significant positive association between fatigue mitigation strategy and fatigue perception for morning types (see **Fig. 1**). For evening types, there was no relationship between the degree to which they perceived that changes are needed to address pilot fatigue and the use of limiting light exposure as a fatigue mitigation strategy. However, for morning types, those who believed changes are needed to address pilot fatigue are more likely to use a strategy of limiting light exposure than those who did not share this belief. In addition, there were three other moderation models that approached significance, suggesting that other mitigation behaviors might be influenced by circadian typology (see Table III for these models).

Table III. Moderation Analyses.

MULTIPLE REGRESSION MODELS				SIMPLE SLOPE TESTS		
OUTCOME PREDICTOR	**B**	**SE_B**	**F**	**MODERATOR**	**B**	**SE_B**
Light						
Changes	0.81**	0.27	6.67**	−1 SD MEQ	0.09	0.34
MEQ	0.05*	0.02		+1 SD MEQ	1.54**	0.39
Changes × MEQ	0.09**	0.03				
Pattern						
Community	−0.26	0.22	2.76†	−1 SD MEQ	−0.88*	0.35
MEQ	0.01	0.03		+1 SD MEQ	0.36	0.25
Community × MEQ	0.08*	0.03				
Pattern						
Personal	−0.05	0.19	2.45†	−1 SD MEQ	−0.60†	0.30
MEQ	0.01	0.03		+1 SD MEQ	0.51†	0.25
Changes × MEQ	0.07*	0.03				
AvORM						
Leadership	0.24	0.32	2.39†	−1 SD MEQ	−0.80	0.48
MEQ	0.02	0.04		+1 SD MEQ	1.28*	0.54
Leadership × MEQ	0.13*	0.05				

$df1 = 3$, $df2 = 17$ for multiple regression models.
† $P \leq 0.10$, * $P < 0.05$, ** $P < 0.01$.

DISCUSSION

Similar to previous studies,[2] a majority of participants believe that fatigue is a serious safety concern for the air mobility community, have personally felt concerned about their fatigue levels, and also believe that changes need to be made within the community to address pilot fatigue. Participants tended to report using exercise as a fatigue mitigation strategy the most given the options on the survey. Participants usually did not reference the performance effectiveness graph before a mission. This is surprising given that this graph can be used as a resource to help plan fatigue mitigation strategies and to create a greater awareness of potential fatigue levels during the mission. Perhaps the fact that aircrew can only access updated graphs if they have a reliable, authorized, and available Internet connection during the mission (which is often not the case) prevents individuals from referencing the graph. Alternatively, aircrew members' possible uncertainty regarding the accuracy of the model-generated sleep patterns, upon which the fatigue predictions are made, might have undermined their trust in the utility of the graphs.

The only fatigue mitigation strategy to have direct significant and approaching significant associations with fatigue perceptions was limiting light exposure. None of the fatigue perceptions were directly associated with performance effectiveness graph usage. Our moderation analyses

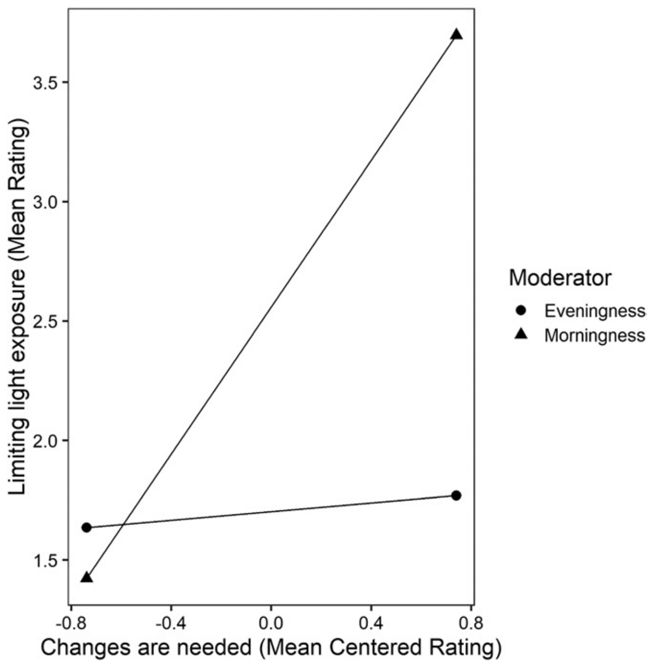

Fig. 1. Interaction between circadian typology and perceptions that changes need to be made to address pilot fatigue on limiting light exposure. Limiting light exposure (Light) values are mean ratings, perceptions that changes need to be made to address pilot fatigue (Changes) values are mean centered ratings, and the moderator, circadian typology, values are mean centered ratings 1 SD above the mean (Morningness) and 1 SD below the mean (Eveningness).

suggest that circadian typology might affect the relationship among fatigue perceptions (both self-reported experiences of fatigue and perceptions about fatigue in the community) and fatigue mitigation behavior. Specifically, these analyses suggest that aircrew who believe fatigue is an issue both personally and community-wide might be more likely or less likely to use fatigue mitigation strategies based on whether they tend to be morning types or evening types, respectively. It is possible that morning type aircrew might have a tendency to experience more fatigue given certain flight schedules or might be more self-aware of fatigue compared to evening types and, as a result, use certain fatigue mitigation strategies, specifically strategies involving zeitgebers, to combat fatigue. Future research should further examine the relationships between circadian typology, objective and subjective measures of fatigue, flight schedules, and fatigue mitigation strategies.

Future research examining moderation effects of circadian typology might provide an impetus for organizations to tailor fatigue risk management programs based on aircrew circadian typology, a suggestion that has been offered by other researchers.[12] For example, programs that offer fatigue risk mitigation education and resources to aircrew, such as AvORM, could suggest specific mitigation strategies based on circadian typology. In addition, the scheduling tool and underpinning biomathematical fatigue model used within AvORM do not take into account individual differences. It might be beneficial to include individual differences such as circadian typology within the model to help improve performance effectiveness predictions.

The current pilot study has limitations that should be noted. We used a small convenience sample which might have limited our ability to find significant relationships that actually exist and limits generalizability to other aircrew communities. In addition, it is possible that we might suffer from sampling bias, as aircrew who believe fatigue is an issue in the air mobility community might have self-selected into our study. Our target population was small and, given the demands of the larger study, it was difficult to obtain large amounts of data from this population. Another limitation of the current study was the cross-sectional nature of the initial questionnaire. As a result, we can only discuss associations between variables, not causation. Given the scope of the larger study, a comprehensive longitudinal examination of these variables was not practical in an operational environment. Given the small sample, it is difficult to include individuals with extreme eveningness or morningness as these individuals only make up 10–15% of the population and a majority (60–70%) of individuals fall in the intermediate category.[11] In the pilot study, a majority of individuals were intermediate evening, intermediate morning, or moderate morning, with only one individual being moderate evening. As a result, our sample was biased toward morning individuals. Additionally, the fatigue perception and fatigue mitigation strategy and resource questions were single nonstandardized research items. To our knowledge, there are no existing standardized instruments concerning general fatigue perceptions in regard to the aviation community (in contrast to standardized scales and items concerning fatigue experiences/measurement) or fatigue mitigation strategies. However, our results were similar to other studies examining fatigue perceptions with study-developed items. Lastly, we included a limited number of fatigue mitigation strategy choices, as well as fatigue perceptions, a factor future research can expand upon.

Although organizations have implemented policies, guidelines, and FRM programs to combat fatigue, it still remains a concern and issue for aircrew. The current study provides additional support for this assertion within the air mobility community. AMC's FRM program provides useful information and tools to help assess and mitigate fatigue; however, there is opportunity to improve this program based on observed aircrew behavior and factors. The current study suggests that individual differences such as circadian typology might affect aircrew fatigue-related actions and perceptions, important factors in the efficacy of FRM. Future research should continue to examine underlying causal factors and possibly incorporate this knowledge in FRM programs.

ACKNOWLEDGMENTS

The views presented in this paper are those of the authors, and do not represent the official position of the United States Air Force or Department of Defense. Dr. Megan Morris completed a majority of this work as a contractor with Ball Aerospace. Maj. Jennifer Howland and Capt. Kelly Amaddio completed a majority of this work while at the Lessons Learned and Assessments Division at Air Mobility Command (AMC/A9L). This research was funded in part with support from the Defense Health

Agency, Joint Program Committee on Military Operation Medicine, Fatigue Mechanisms Working Group.

Financial Disclosure Statement: The authors have no competing interests to declare.

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