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Safety Climate Assessment: The Implementation of Psychological Fatigue Indicators in Airline Fatigue Risk Management Systems

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Abstract

In commercial aviation, safety is of paramount importance and an indispensable prerequisite for building extensive, dependable air transportation networks. Several aspects affect airline safety, from training to operations and organizational conditions. The critical importance of aircrew fatigue has long been identified; in 2016, nearly 20% of all accidents under investigation by the US NTSB had it listed as one of the probable causes or contributing factors. This study aims to evaluate the utility of adding psychological fatigue elements to the fatigue self-report and survey tools currently used by airlines. Research goals include identifying psychological fatigue markers in airline fatigue survey forms, analyzing these instruments to determine their sensitivity in identifying fatigue that is not exclusively attributed to physiological factors, and investigating potential improvements of these instruments for use in commercial aviation. The authors examined the effect of psychological and physiological fatigue factors on the aviation industry's overall state and dynamics, especially given the consequences of the recent pandemic. Analysis indicates that incorporating psychological items to existing fatigue reporting and survey instruments significantly changes the measured fatigue levels, suggesting that measuring physiological fatigue alone may not be sufficient to accurately determine overall fatigue levels. The proposed implementation of psychological Fatigue Indicators identifies critical and significant risks related to the current Fatigue Risk Management System, especially in atypical periods when the aviation industry is experiencing substantial disruptions and psychological fatigue is prevalent.

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Keywords: Fatigue; Fatigue Risk Management Systems; Safety Management Systems; Aviation Safety; Physiological Fatigue; Psychological Fatigue

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1. Introduction

Even though fatigue is deemed crucial for the operational safety of civil aviation, a precise, widely accepted definition for the concept is still being debated (Bartley and Chute 1947, Cameron 1973). Different definitions have been proposed over the years, some of which have gained significant exposure and acceptance due to being included in regulatory documents (ICAO 2013, chap. 1) or extensively cited in academic papers. Other definitions remain relatively obscure and largely unknown outside their specific domains. Furthermore, the unitary or multidimensional nature of the concept has been the subject of much debate (Earle 2004, section 1.1). Growing evidence seems to suggest that fatigue is a multifaceted construct with at least two distinct components (Shen, Barbera, and Shapiro 2006), a physiological component related to excessive energy consumption and insufficient replenishment of physical resources through adequate rest and a psychosocial component characterized by a state of general weariness and reduced motivation (Aaronson et al. 1999).

An airline safety management system must include structures for reporting and managing fatigue. The widely used Fatigue Risk Management System (FRMS) approach is a "data-driven approach of continuously monitoring and controlling fatigue-related safety concerns" that, according to the International Civil Aviation Organization (ICAO 2015), aims to create tools and procedures through which service providers may manage risks associated with fatigue. Traditionally, data collection techniques have focused on the physical and biomechanical components of the activity, in order to identify fatigue levels and circadian rhythm disturbances brought on by the continuous operations of modern commercial aviation (ICAO 2015: 23). To determine a "degree of alertness," a typical fatigue report looks at work / rest patterns, preceding duty duration, sleep quality, and other relevant information (UK CAA 2007). The psychological component of fatigue is rarely addressed by specific items in the fatigue report forms in widespread use in the industry. This might result in the misidentification of fatigue levels, particularly during significant medium- to long-term operational disturbances affecting front-line workers psychologically (EASA 2020a). During these times, psychological factors significantly the variability of operator performance (Morgul et al., 2020). Due to the pro-cyclical nature of the aviation industry and its disproportionate reliance on a highly skilled and expensive workforce, an organization's ability to quickly reduce labor costs and implement large-scale optimizations (like restructuring), seems essential to its survival (UK CAA 2020). These, among other measures, typically cause disruptions to standard work patterns and cause a range of psychological reactions among aviation workers, primarily increased uncertainty about future employment and health concerns (EASA 2020b).

2. Materials and Methods.

The multidimensionality of fatigue necessitates that fatigue risk management self-reporting and survey instruments are sensitive to both the physical and psychological dimensions of the construct. Items included in these scales should quantify fatigue in either of these dimensions, in order to facilitate efficient risk management measures aiming to preserve operational safety. Furthermore, fatigue assessments should provide the opportunity to perform three general types of comparisons (Frone and Tidwell 2015) within the FRMS framework: The level of work-related fatigue across groups of aircrew members with frequently disparate characteristics, the strength of the relationship between specific factors and the resultant fatigue level and, finally, an estimation of fatigue levels through predictors usually codified as Safety Performance Indicators. An additional number of considerations for measuring fatigue exist in an operational context – instruments cannot be excessively long and, consequently, only a limited number of questions can be included. Furthermore, practical constraints related to dissemination, completion, and submission of reports by operational personnel are considered, creating limitations that are not necessarily present in a laboratory environment (Millar 2012).

This research was conducted using a Simple Mixed Methods (Saunders, Lewis, and Thornhill 2019, s. 5.6-5.7) cross-sectional, sequential exploratory design composed of a literature review, a qualitative, and a quantitative phase. Following the qualitative stage, a fatigue assessment questionnaire was developed, tested (Hassan, Schattner, and Mazza 2006), and analyzed to reveal potential shortcomings of traditional approaches to fatigue reporting.

2.1 Literature Review

This phase of the study focused on three areas. Firstly, thirty-nine studies describing current theories on the nature of fatigue were reviewed, with special focus on the uni- or multi-dimensional nature of the construct. Secondly, and in support of the previous topic, regulatory documents on the management of fatigue were reviewed, as published either by the International Civil Aviation Organization (ICAO 2020) or national authorities (CASA 2013). The intention of these two phases was to provide an empirical foundation for the basic premise of this study and, furthermore, to identify potential shortcomings of current generation fatigue risk management systems (FRMS). It was anticipated that FRMS schemes in widespread adoption in the industry would be found lacking in the identification of fatigue that is not directly attributed to well-understood physiological causes (for instance, irregular work shift patterns or frequent disruptions of circadian rhythm stability). Lastly, eighteen fatigue identification instruments were reviewed for potential inclusion in the prototype questionnaire developed through this study. The majority of these were found to target physiological fatigue, with a small number addressing psychological fatigue that was, in most cases, related to chronic medical conditions. The complete list of instruments reviewed is presented in Table 1.

Table 1. Fatigue assessment instruments

Scale	Number of items	Response format	Measure outputs Reference
Fatigue Questionnaire (FQ)	14	Four-point Likert scale	Physical and mental (Chalder et al. 1993)
Fatigue Severity Scale (FSS)	9	Seven-point Likert scale	Primarily clinical applications (Krupp et al. 1989)
Multi-dimensional Assessment of Fatigue (MAF)	16	10-point Likert scale	Includes both physiological and psychological fatigue items (MAF - Multidimensional Assessment of Fatigue n.d.)
Short Form Survey – 36 (SF-36 v1)	36	Two- to six-item Likert scale	Includes physiological, mental and psychological fatigue items (RAND Corporation n.d.)
Chalder Fatigue Scale (CFS)	14	Four-item Likert scale (Less than usual to Much more than usual)	Physical and mental fatigue items (Chalder et al. 1993)
SAM Form 202			Specific to military aviation. Both physical and psychological fatigue items (Samn and Perelli 1982)
Stanford Sleepiness Scale (SSS)	7	Seven-point Likert scale	Primarily for the assessment of sleepiness (Shahid et al. 2011b)
Swedish Occupational Fatigue Inventory (SOFI)	20	Six-point Likert scale	Primarily clinical application, items measuring lack of energy, physical exertion, physical discomfort, lack of motivation and sleepiness (Åhsberg and Gamberale 1998)
Fatigue Assessment Instrument – (FAI)	29	Eleven-point Likert scale	Four sub-domains. Mostly clinical applications, but has been used (Ma et al. 2014) in an aviation related study (Schwartz, Jandorf, and Krupp 1993)
Visual Analogue Scales for Fatigue (FAS-V)	18	Ten-point Likert scale.	Items for physical and mental fatigue (Shahid et al. 2011c)
Samn-Perelli (SP) Fatigue Scale	7	Seven-point Likert scale	Measurement of fatigue states. High test-retest reliability (Miller and Narvaez 1986). Applied on military and civilian pilot populations (Gander et al. 2015)

Karolinska Sleepiness Scale (KSS)	1	10-item Likert scale	Estimate of level of sleepiness. Validated through objective measures (EGG activity), (Kaida et al. 2006)
Multi-dimensional Fatigue Inventory (MFI-20)	20	Five-point Likert scale	General physical, psychological and mental fatigue (Smets et al. 1995).
Fatigue Impact Scale – FIS	40	Four-point Likert scale	Items estimating cognitive, physical, and psychosocial fatigue (Fisk et al. 1994).
Brief Fatigue Inventory – BFI	9	Eleven and ten-item Likert scales.	Mostly clinical applications (long term sickness), (Mendoza et al. 1999)
Three-dimensional Work Fatigue Inventory (3D-WFI)	18	Five-point Likert scale	Physical, mental and emotional fatigue items (Frone and Tidwell 2015)
Mental Fatigue Scale (MFS)	15	Four-point Likert scale but further divided into .5 point intervals.	Physical, mental and psychological fatigue items (Chalder et al. 1993)
Piper Fatigue Scale	27	Variable by question, Likert type	Affective, intensity, sensory, and temporal dimensions of fatigue (Piper et al. 2015)

Results from the literature review seem to support the notion that fatigue is a multidimensional construct, comprised at a minimum by two distinct components - a physiological component related to excessive energy consumption and insufficient replenishment of physical resources through sufficient rest, and a psychosocial component characterized by a state of general weariness and reduced motivation (Aaronson et al. 1999). Furthermore, FRMS related data collection activities seem to be overly focused on the physical aspects of the task and rarely address the psychological component of fatigue through specific questionnaire items. It is hypothesized that this could lead to a misidentification of overall fatigue levels, especially in times when psychological fatigue is thought to prevail.

2.2 Qualitative Phase

The qualitative phase of the study aimed to inform the development of the fatigue risk assessment instrument used in the subsequent quantitative phase. In light of the limited number of instruments available for assessing psychological fatigue in aviation, it was envisioned that this phase would provide sufficient empirical data to facilitate the development of questionnaire items targeting the construct. Primary qualitative data was acquired through semi-structured interviews with select Subject Matter Experts (SME). A total of fifteen potential participants were selected for interview. Fourteen accepted the invitation, and one declined due to scheduling conflicts. A pilot's professional involvement in commercial or military aviation was required for inclusion in the SME group; managerial experience in fatigue risk management, fleet management, or crew scheduling was considered an advantage. Furthermore, selection was also dependent upon role diversity, overall experience (Fig. 1), interest in the topic of fatigue, relevance, currency, and the desire to participate (Manea 2020). Finally, participants were chosen (or excluded) based on their availability during the relevant stage of the study and lack of organizational affiliations.

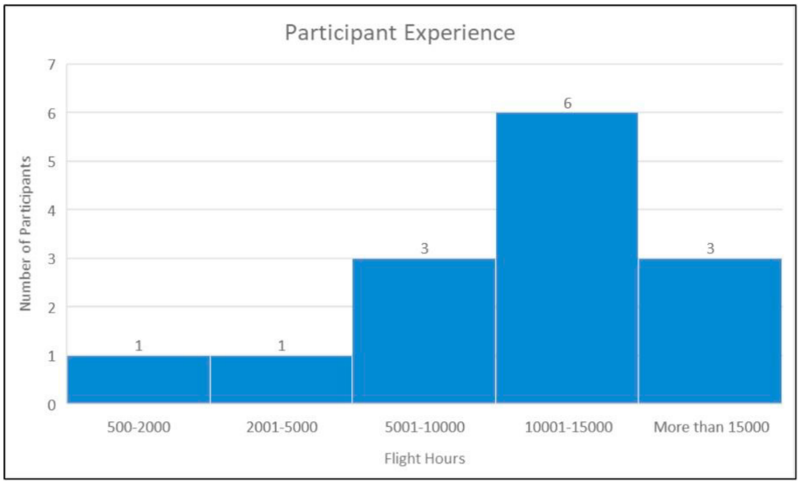

Fig. 1. Interview participants experience level distribution.

Data collection activities were conducted in May 2021. The duration of each interview was 20 to 30 minutes, and all of them were conducted online due to public health considerations and practical issues. All interviews were recorded and transcribed by the researcher. The development of the interview questions was informed by the topics identified during the literature review and addressed a total of four top-level thematic areas. A categorical classification of interview questions (Table 2) and the complete interview plan can be provided through electronic mail upon request to the authors. Collected data were transcribed and interpreted using the Template Analysis procedure described by King (2021), the line-by-line mapping and grouping process recommended by Merriam and Tisdell (2015) and the keyword-coding based approach recommended by Flick (2018).

Table 2. Classification and distribution of interview questions

Interview phase	**Thematic area**	***N***
Introductory comments	Not applicable	
Demographic questions	Not applicable	5
Discussion	Level, nature, causes and effects of fatigue	9
	Effects of organizational disruptions (esp. the effect of the SARS-COV-2 pandemic)	4
	Organizational effects on fatigue	11
	Additional remarks	1
Closing comments	Not applicable	
Total	Not applicable	30

Following the analysis of the data collected from the interviews, three distinct thematic areas emerged from the data, comprised of eleven themes (Table 3). A comprehensive list of encoding indicators selected for each theme can be provided to interested parties upon request.

Table 3. Summary of thematic areas and themes

Thematic area	**Theme**
I. Fatigue	A. Nature of fatigue
	B. Effects of fatigue
	C. Correlation between age and fatigue level
II. Organizational factors	A. Fatigue reporting culture of operator
	B. Consideration of psychological fatigue by operator
	C. Management of layoffs
	D. Rostering practices

A total of six questionnaire items were developed following the analysis of qualitative data obtained during this phase of the study, targeting both psychological and physiological fatigue (Table 4).

Table 4. Survey items developed through qualitative data analysis

Item number Narrative	Main category	Sub-category	Thematic code
16 I feel reluctant to report fatigue to my operator's management.	Indicator of psychological fatigue	Indicator of organizationally induced fatigue	II.A.1
17 I think my employer's rest scheduling is very poor.	Indicator of physiological fatigue	Indicator of organizationally induced fatigue	II.D.3
18 Physical fatigue is a major issue in the company I work for.	Indicator of physiological fatigue	Indicator of organizationally induced fatigue	IV.B.3
21 I find it difficult to keep studying for work.	Indicator of psychological fatigue	Indicator of mental fatigue	I.B.1
24 When I wake up, I feel just as tired as when I went to bed.	Indicator of physiological fatigue	Indicator of physical fatigue	I.B.3
27 Controlled rest in the flight deck is an absolute necessity.	Indicator of physiological fatigue	Indicator of physical fatigue	IV.A.1
31 I have caught myself falling asleep during critical phases of flight.	Indicator of physiological fatigue	Indicator of physical fatigue	I.B.4

III. FRMS	A. Overall FRMS suitability B. Suitability of fatigue reporting instruments C. Need to update FRMS reporting instruments
IV. Combined	A. Controlled rest practices B. Fatigue levels during operations

The psychological factor of the instrument was developed using items from validated scales, or self developed based upon the results of the qualitative phase. In total is comprises sixteen questionnaire items. Table 5 describes these items, along with the origin and psychological fatigue component targeted by the item.

Table 5. Psychological fatigue items

Item number	Fatigue component	Origin
6	BEHAV[a]	Chalder et al. (1993)
7	BEHAV	Modified Fatigue Impact Scale (MFIS) - Frith and Newton (2010)
8	OCCU[b]	Goldenhar, Williams, and G. Swanson (2003)
9	OCCU	Goldenhar, Williams, and G. Swanson (2003)
10	BEHAV	Goldenhar, Williams, and G. Swanson (2003)
11	BEHAV	Goldenhar, Williams, and G. Swanson (2003)
12	BEHAV	Goldenhar, Williams, and G. Swanson (2003)

13	OCCU	Generic Job Stress Questionnaire (NIOSH n.d.)
14	OCCU	Goldenhar, Williams, and G. Swanson (2003)
15	OCCU	Generic Job Stress Questionnaire (NIOSH n.d.)
16	ORGAN[c]	Self-developed, thematic code II.A.1
19	ORGAN	Goldenhar, Williams, and G. Swanson (2003)
20	BEHAV	Depression Anxiety Stress Scales (DASS) questionnaire
21	MENT[d]	Self developed, thematic code I.B.1
26	BEHAV	Generic Job Stress Questionnaire (NIOSH n.d.)
30	PSYM[e]	Swedish Occupational Fatigue Inventory (SOFI). Åhsberg et al. (2000)
33	BEHAV	Generic Job Stress Questionnaire (NIOSH n.d.)

[a.] Behavioural indicator of psychological fatigue
[b.] Indicator of occupationally induced fatigue
[c.] Indicator of organizationally induced fatigue
[d.] Indicator of mental fatigue
[e.] Indicator of physical fatigue.

Similarly, the physiological fatigue component of the instrument comprised of items that were either included in previously validated scales or self-developed. A total of thirteen items were included in the final version of the instrument (Table 6).

Table 6. Physiological fatigue items

Item number Narrative	**Fatigue component**	**Origin**
17	ORGAN[a]	Self developed, thematic code II.D.3
18	ORGAN	Self developed, thematic code IV.B.3
22	PSYM[b]	Occupational Fatigue Exhaustion Scale (OFER) (Winwood et al. 2006, Winwood et al. 2005)
23	PSYM	Short Form Survey – 36 (SF-36) - Aaronson et al. (1999)
24	PSYM	Self developed, thematic code I.B.3
25	PSYM	Short Form Survey – 36 (SF-36) - Aaronson et al. (1999)
27	PSYM	Self developed, thematic code IV.A.1
28	PSYM	Fatigue Assessment Scale (FAS) - Shahid et al. (2011)
29	PSYM	Fatigue Assessment Scale (FAS) - Shahid et al. (2011)
31	PSYM	Self developed, thematic code I.B.4
32	PSYM	Three-dimensional Work Fatigue Inventory (3D-WFI) Frone and Tidwell (2015)
34	PSYM	Fatigue Impact Scale (FIS) - Frith and Newton (2010)
35	PSYM	CASA (2013)

[a] Indicator of organizationally induced fatigue
[b] Overall indicator of physiological fatigue

2.3 Quantitative Phase

Primary quantitative data were acquired through an internet-mediated survey (Fink 2013). The instrument was disseminated to a sample (N = 86) of professional pilots, and data were collected during the first half of 2021 (Chazapis 2021). The survey instrument was designed based upon existing fatigue measurement scales selected following the literature review and further informed by the results of the qualitative phase. It consists of the following five sections:

- Part 1: Informed consent
- Part 2: Factual, demographic, and occupational information
- Part 3: Physiological fatigue assessment
- Part 4: Psychological fatigue assessment
- Part 5: Open-ended question

The first four parts of the questionnaire comprise closed questions (Fink 2013). Responses to parts three and four of the survey were provided on a five-point Likert scale ("Fully Disagree" to "Fully Agree" with an actual neutral point). Several items employed reverse-coding (Coolican 2019: 201) and were re-adjusted before analysis. Limited randomization of condition order (Coolican 2019: 79) was performed to mitigate against order effects; nevertheless, the nature of the questions rendered the extensive application of this method unfeasible. Lastly, a thematic analysis was performed on the open-ended section of the questionnaire. The final version of the instrument can be provided to interested parties upon receipt of a request through electronic mail.

Survey participants were recruited using non-probability, self-selection sampling (Saunders, Lewis, and Thornhill 2019: 297). The target population was professional pilots currently or formerly employed in commercial or military aviation. Student or private pilots were excluded from the study through demographic filtering to ensure that participants possessed a suitable level of exposure to working conditions in the industry before participation. The selection of non-probability sampling was in line with the exploratory and internet-mediated nature of the survey and the difficulty in obtaining a suitable sampling frame (Saunders, Lewis, and Thornhill 2019:316). An initial number of participants were recruited through convenience sampling using direct electronic mail invitations that included a request for further disseminating the fully anonymous link to the survey form (Coolican 2019: 51). Distribution of participant age and experience levels are found in Fig. 2.

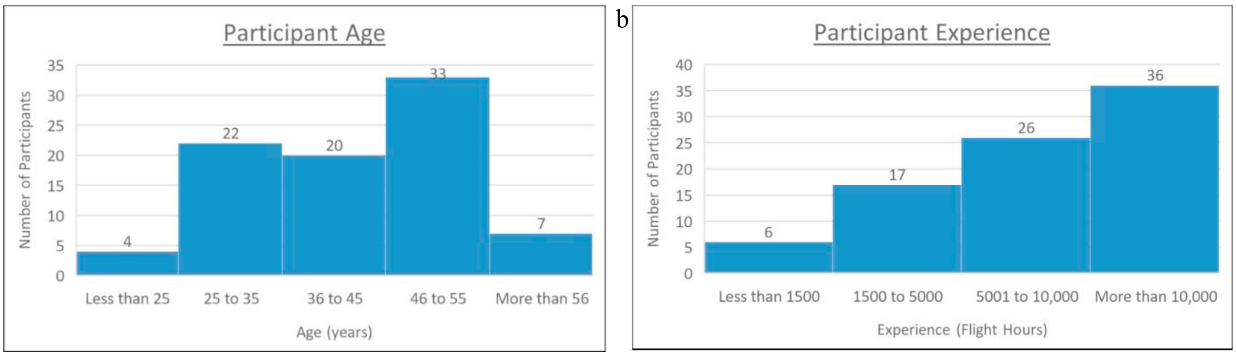

Fig 2. (a) Questionnaire participant age and (b) operational experience distributions.

2.4 Analysis

Data analysis was based on fatigue scores (the dependent variable) obtained at two levels of the independent variable (IV) per case:

- Using only the physiological fatigue items of the instrument
- Using both the physiological and the psychological fatigue items

Data collected using the Likert-scale responses were analyzed using Student's *t*-Test or the Wilcoxon signed-rank test, depending upon the normality of the data. Violations of normality were assessed using D'Agostino - Pearson K^2

goodness-of-fit and Shapiro-Wilk tests at $\alpha < .05$. Bidirectional (two-tailed) tests were performed since the effect of adding psychological fatigue items to the instrument could not be estimated in advance. A per standard practice $p < .05$ was considered statistically significant. The instrument demonstrated high internal consistency and scale reliability, with Cronbach's-α values of .92 and .89 for the overall instrument and the psychological fatigue items only respectively. Inter-item correlations and α scores resulting from deleting a specific item can be found at Table 7.

Table 7. Inter-item correlation and Crombach-*α* values

Item number	Scale Mean if Item Deleted	Corrected Item-Total Correlation	Cronbach's α if Item Deleted	Item number	Scale Mean if Item Deleted	Corrected Item-Total Correlation	Cronbach's α if Item Deleted
Q6	84.27	.62	.914	Q21	83.84	.64	.914
Q7	84.50	.49	.916	Q22	83.84	.69	.913
Q8	84.38	- .05	.924	Q23	84.02	.36	.918
Q9	84.91	.54	.916	Q24	84.48	.69	.914
Q10	85.05	.35	.918	Q25	83.84	.63	.914
Q11	84.65	.55	.916	Q26	84.95	.49	.916
Q12	83.73	.62	.914	Q27	83.29	.14	.920
Q13	83.85	.23	.920	Q28	83.87	.71	.913
Q14	84.17	.44	.917	Q29	83.57	.58	.915
Q15	84.85	.63	.914	Q30	84.74	.49	.916
Q16	83.65	.56	.915	Q31	84.79	.34	.919
Q17	83.53	.59	.915	Q32	83.71	.43	.917
Q18	83.74	.59	.915	Q33	83.98	.58	.915
Q19	83.55	.72	.913	Q34	84.88	.33	.918
Q20	84.07	.51	.916	Q35	84.30	.55	.915

Conversely, convergent/discriminant validity (Streiner, Norman, and Cairney 2015) was assessed by examining the correlation between psychological fatigue and the previously validated physiological fatigue items. The selection of a subset of questions for inclusion in the prototype FRMS self-report fatigue questionnaire was predicated on three factors: Initially, survey data were analyzed using Pearson's r inter-item correlation analysis (Robson and McCartan 2016: 429) to form groups of highly correlated survey items. Subsequently, Cronbach's α scores were used to rank items within each group based upon their effect on scale reliability, with items having the most adverse effect (in the form of a lower α score if removed) ranked at the lowest level. Finally, items from each group were selected based on their ranking (high to low) and suitability, with items belonging to the behavioral and mental fatigue categories, considered the most appropriate for inclusion in a short, self-survey instrument (Chazapis 2021).

3. Results and Discussion

The results from the qualitative phase of the study seem to support the basic assumption that there is a significant psychological component to fatigue that current generation FRMS schemes fail to assess properly. The analysis evaluated the following hypothesis:

- H_o: There will be no significant difference in the mean level of fatigue identified by the original (physiological items only) and the expanded version of the questionnaire
- H_α: There will be a significant difference in the mean level of fatigue identified by the original (physiological items only) and the expanded version of the questionnaire

Results indicate that the addition of psychological fatigue indicators led to an overall reduction in fatigue scores (M =2.90, SD = .58) compared to the version containing only physiological fatigue indicators (M = 3.02, SD = .63) and, consequently, a decrease (M = .09, SD = .21) in the mean fatigue score produced by the instrument. Since the data met parametric assumptions, a paired samples t-Test was conducted, and the difference was significant, $t(85) = 3.76$, $p < .05$, two-tailed.

Based on the results of the two tests, we can reject the H_o at the .05 significance level and accept the H_α stating that adding the psychological fatigue assessment items cause a significant change to the fatigue scores produced by the survey instrument.

Most interview participants appear to support the notion that in times of major crises in aviation, the nature of fatigue and its overall level will be significantly altered. Figure 3 provides an example of the encoding process used for the qualitative analysis. For thematic area I (Fatigue), theme A (Nature of fatigue), there were a total of 64 comments made during the interviews. The majority of them (N=61) seem to support the notion that the nature of fatigue has changed after the COVID-19 pandemic, while two participants believe it has remained the same and one expressed a neutral opinion. These views were, subsequently, encoded to thematic codes I.A.3, I.A.1 and I.A.2 respectively.

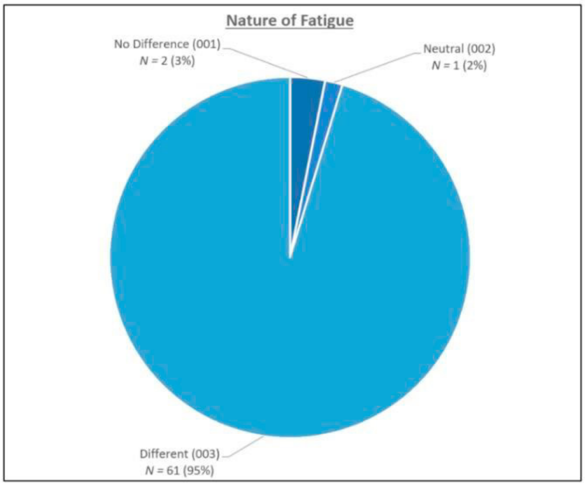

Fig 3. Interview participant perceptions on the nature of fatigue pre- and post-pandemic.

Interviewees partially attributed these effects to organizational factors, more specifically to a fundamental lack of consideration for the impact of psychological factors on front-line operator fatigue, which was made worse by an overall unfavorable culture toward voluntary fatigue reporting, or at best, a neutral one. Participants noted that this appeared to be connected, at least partly, to a general lack of understanding of the multidimensional nature of fatigue. Large-scale operational disruptions like the COVID-19 pandemic present a unique opportunity to assess the effectiveness of well-established safety management practices on operator fatigue. The management of layoffs and rostering methods were noted as critical fatigue-inducing practices at an organizational level during the literature review, further emphasized by participants. Both of these activities are necessary for an organization to run normally. Still, the epidemic's economic crisis increased its intensity, which worsened its psychological effects on front-line workers. According to SME interviews and the literature study, there is a need for precise regulatory guidelines on including a psychological component in the fatigue management systems used by enterprises. Participants agree almost unanimously that FRMS techniques are inadequate for a thorough assessment of fatigue in their current state.

Additionally, the conditions in the industry have drastically changed, rendering existing databases of potential fatigue-related hazards outdated and unrepresentative of the post-pandemic status of the sector (IATA 2020a, 2020b). This may hinder the overall operation of FRMS systems, particularly for their proactive and predictive components, which could reduce the effectiveness of those systems in promoting aviation safety. Participants have underlined the need to reassess the content of the fatigue survey and self-report instruments utilized within the overall structure of these systems and appear to concur that an updated standard for FRMS is required.

Quantitative findings show that adding a psychological component to an instrument designed to measure physical fatigue levels can drastically alter results. This is in line with the study's primary research question, the results of the literature review, and the qualitative section. Additionally, even though there are no domain-specific or previously validated collections of questionnaire items for evaluating psychological fatigue (especially ones that are relevant to aviation), it seems possible to create a set of questions that, when added to an existing aviation fatigue instrument, won't lead to a decrease in validity or reliability. Studies on creating such an instrument appear to be appropriate in light of the identified need for an overall reevaluation of FRMS approaches discussed in the previous paragraph. The direction of the effect produced by adding the psychological tiredness items was a notable discovery of the quantitative phase. Because the study was conducted during or right after the start of the pandemic, when psychological stressors were believed to be abundant, it was anticipated that adding items sensitive to psychological fatigue would result in an overall increase in the levels of fatigue measured by the instrument. Although a statistically significant effect is present as expected, the data show that it is actually producing an opposite direction of what was anticipated. This is implied by the instrument's lower overall level of fatigue when both aspects are considered as opposed to the level measured only by the physiological fatigue items. The study's primary data collection activities were carried out in May and June 2021, when there were clear signs of an industry-wide recovery and a reversal in trends related to employment levels. Most organizations were transitioning from a phase of staff reductions to a slow resumption of recruitment, and this might explain some aspects of this discrepancy. Several participants reported a considerable rise in workload and subsequent physiological, but not psychological, exhaustion levels due to the gradual restart of activities, which were indicators of the establishment of an optimistic outlook during the qualitative phase of the study. If this study had been conducted a few months earlier, when businesses were still feeling the full effects of the pandemic and mass layoffs were more widespread, participant responses and the survey's outcomes might have been different.

Additionally, these findings can potentially point to psychological characteristics particular to pilots (intrinsically high levels of job satisfaction, and an overall tendency towards optimism). The literature appears to support this viewpoint. However, further research would be needed in order to confirm and potentially quantify such effects.

Although the study targeted pilots, its basic premise applies equally to other operational roles within aviation, with Cabin Crew and Dispatchers sharing comparably elevated levels of exposure to fatigue and task criticality with pilots. The literature review reveals that little research has been performed on a comprehensive assessment of fatigue for these roles. Follow-on studies may investigate if there is merit in addressing this shortcoming by developing fatigue assessment instruments specific to these groups.

The methodological limitations of this study potentially offer further opportunities for follow-on studies of the subject, as the study used a cross-sectional design that can create concerns concerning the generalizability of the results. This is especially true for times that are atypical and unrepresentative of the normal state of the aviation industry. A follow-on study employing a longitudinal design may help alleviate some of these concerns. Moreover, as this study uses a non-random sample through the availability of a suitable sampling frame, targeting a specific organization of sufficient size might provide higher validity and generalizability of results. Follow-on studies might seek to validate the prototype fatigue self-report and survey instruments through a test deployment in real-world operating conditions and then solicit subject matter expert views from within the organization. Finally, complete sample randomization (Miles and Banyard 2007: 54–55) was not followed for practical reasons related to the availability of resources, time constraints, and unavailability of a suitable sampling frame. Researchers conducting follow on studies may consider using a random-sample design that might help provide results of higher validity.

4. Conclusion

The study presented empirical evidence that fatigue is a multidimensional construct connected to psychologic and physiological factors. Both of these factors must be considered and carefully examined if the high level of aviation safety is to be maintained, especially in times of significant disruptions that threaten the efficacy of well-established risk management systems. Underestimating the effects of such events on fatigue experienced by flight crews can have substantial repercussions, and organizations must ensure that additional measures to quantify these risks and provide efficient mitigation against them are introduced. Furthermore, since accurate operational data, in the form of comprehensive risk factor databases, is a prerequisite for the efficient operation of these systems, operators should ensure that methods and instruments used to measure fatigue levels are valid and reliable even, and primarily, in times of substantial changes in the nature or tempo of their operations. Finally, they should ensure a favorable climate towards hazard reporting, especially during economic or operational difficulties when front-line operators can be negatively predisposed to submitting voluntary hazard reports. Even though the duality of fatigue seems undisputed, an overriding issue with the lack of in-depth analyses of the distinct types of fatigue remains, creating difficulties in developing instruments that can accurately measure fatigue in operational settings. One of the main aims of this study was to highlight the need for such analyses and encourage operators to adopt a more holistic approach towards fatigue, including its psychological fatigue and, potentially, other aspects of the construct as they become unveiled by research.

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