An Analysis of Fatigue and Its Characteristics: A Survey on Chinese Air Traffic Controller

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Abstract. Previous research has shown that fatigue may reduce alertness and negatively impact job performance [1]. An over fatigued worker may increase the probability of an accident or incident. The purpose of this research study was to examine fatigue conditions and identify fatigue characteristics among air traffic controllers in China. Researchers utilized a survey to gain a clearer understanding of participant perceptions pertaining to fatigue. Survey items consisted of the following constructs: subjective fatigue, sleep quality, working factors, daily life factors, and personality. The results indicated that sleep quality and workload were major issues that caused the feeling of fatigue in the air traffic controllers surveyed. It is noticeable that daily life impact also contributed to the controller's fatigue.

Keywords: Air traffic controllers · Fatigue · Aviation safety

1 Introduction

The civil aviation industry in China has been rapidly developed in recent years and has become the second largest aviation market in the world after the United States. With the rapid development of the aviation industry, the phenomenon of fatigue is increasingly becoming prominent throughout the civil aviation industry, particularly for air traffic controllers in China. Fatigue may lead to a decreased alertness and raise safety hazards [1]. According to the United Kingdom CHIRP (the Confidential Human Factors Incident Reporting Programme), 13 % of operation errors were directly caused by the controllers' fatigue in the U.K. [2]. Reported by the Xiamen ATC Safety Reporting System in China, 18 % of the errors made by air traffic controllers were associated with fatigue [2]; The National Transportation Safety Board (NTSB) in the U.S. has considered fatigue as one of the most important aviation safety issues that need to be solved [3].

Air traffic controllers in China are facing not only increasing work pressure, but also growing fatigue risks, due to a significant increase in the national air traffic. According to the Xinhua News Agency, Eastern Airlines flight MU2528 failed to contact with the ATC when approaching to Wuhan airport in the year of 2014, because two tower controllers fell asleep on duties. Fortunately this incident did not turn into a fatal tragedy, however, it posed a serious threat to aviation safety [4]. Previous

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researchers have conducted a number of research studies in order to address fatigue and various fatigue assessment methods have been generated.

Fatigue assessment methods mainly involve two categories: one is subjective measurement using questionnaires, such as the NASA-TLX scale, multidimensional fatigue self-assessment scales, Japan fatigue scale, fatigue scale FS-14, and Karolinska sleepiness scale (KSS) [5]; The other category is an objective measurement method by means of instruments, equipment and other auxiliary tools. These methods can record and measure human physiological and behavioral changes of certain indexes to reflect the degree of fatigue. These instruments and tools contain electrical equipment, eye tracking, flicker fusion frequency detectors, head position sensors, etc. [6]. Saroj and other researchers reviewed electroencephalogram (EEG) signals, eye-movement data, and other ways to analyze subjects' performance in driving simulation. Researchers found EEG was one of the most effective indicators for fatigue detection [7, 8].

Although EEG, eye-movement data and other similar methods can accurately reflect one's fatigue, the experimental data is subject to human and environmental impacts. Investigation of fatigue of air traffic controllers is mainly conducted by using fatigue survey questionnaires. Wang Tian-fang conducted a local fatigue self-assessment scale research study [9], whose purpose was to understand fatigue and depression of patients with chronic disease. The researchers of this study developed a survey that consisted of the following parts: Personal information, subjective fatigue assessment, workload factors, sleep status, life event impacts, and personality features. To gain a clearer understanding of air traffic controllers fatigue, the following research questions were addressed:

1. How bad it is? And what are the fatigue characteristics (general, physical, mental, and level of motivation) of participants?
2. How do fatigue and its contributing factors connected?

2 Methods

2.1 Survey Questionnaires

In order to identify risk factors that may lead to controllers' fatigue and understand fatigue characteristics, the researchers designed an air traffic controller fatigue survey questionnaire. The 6 components of the survey are listed in Table 1.

2.2 Reliability and Validity Analysis

Because Pittsburgh sleep quality index has been strictly tested in terms of reliability and validity, and personal information questionnaire, work-related factors questionnaire and life events impact questionnaire are objective investigation to controllers' life and of work-related information, it is not necessary to make an analysis of reliability and validity pertaining to the parts discussed above.

In this study, the researchers conducted reliability and validity analysis for the Subjective Assessment of Fatigue by using SPSS.22.0. Analysis results showed that

Table 1. Survey components.

Items	Purpose and Content
Personal information	Basic personal information included: family, personal living habits, preferences and health information, awareness to fatigue. In addition, basic information such as age, sex, job, growing environment, and education.
Subjective assessment of fatigue	The fatigue scale was designed to investigate controllers' fatigue. This part was based on the multidimensional fatigue inventory MFI-20 and included general fatigue, physical fatigue, mental fatigue and reduced motivation, 16 entries in total. There were 5 points from "not true" to "entirely true". There were 16–80 points in total, each dimension had a score of 4–20 points, and higher scores represent more serious fatigue.
Work-related factors questionnaire	This questionnaire incorporated schedule, workload and work environment factors, altogether 19 items. In terms of scheduling, it mainly investigate controllers' working time, duty time, numbers of overtime, rest after two consecutive hours, and shifts impact on controllers' sleeping habits. In the work survey section, numbers of flights, unusual events handling, operation limitations were mainly contributing to controllers' high workload. As for work environment, mainly investigate controllers rest environment, equipment performance, staffing and training, team characteristics and humanitarian environment.
Sleep quality index	The scale mainly referred to the Pittsburgh sleep quality index (PSQI) [10] which was prepared by the psychiatrist doctor Buysse from the University of Pittsburgh. The questionnaire contained seven dimensions: subjective sleep quality, sleep latency, sleep time, sleep efficiency, sleep disorders, using of medicine and daytime dysfunction. The scale was revised to four dimensions considering the reality of air traffic controller work.
Life events impact questionnaire	Some events in one's daily life whether good or bad, will definitely bring influence to metal state. Therefore, life events are involved as part of the controllers' fatigue investigation. This scale covers seven groups: work related, career, relationships, marriage and family, economic, physiological conditions and system pressure. Seventeen events were taken into account.
Personality traits questionnaire	People with different personalities handles problem differently. In this part, the Big Five Inventory for person traits investigation was used [11]. There were five dimensions involved: extraversion, agreeableness, conscientiousness, neuroticism, and openness. We try to use personality investigation to find out the relationship between personal traits and fatigue.

Cronbach's Alpha coefficient was 0.803, which indicated a high reliability. Additionally, the factor analysis method and the orthogonal variance maximum rotating method were applied. Four factors whose characteristic roots were bigger than 1, and their cumulative variance contribution rated for 84 %. Sixteen factor loadings were bigger than 0.5, which means it had good discriminability.

3 Results

The researchers distributed survey questionnaires to an ATC facility in China, including tower control, approach control, area control, and flight services. Eighty-five survey questionnaires were distributed, and eighty participants completed the survey. Table 2 shows the demographic information.

Table 2. Demographic numerical values

		n = 80
Gender	Male	70 (87.5 %)
	Female	10 (12.5 %)
Age	20～30 years	40 (50.0 %)
	31～40 years	23 (28.8 %)
	41～50 years	17 (21.2 %)
Position	Tower Controllers	20 (25.0 %)
	Approach Controllers	30 (37.5 %)
	Area Controllers	19 (23.8 %)
	Flight Service Controllers	11 (13.7 %)

3.1 Fatigue of Controllers in General

According to the fatigue scoring rules, the scores between 16 and 28 stand for no fatigue. The score span 29–41, 42–54, 55–67, and 68–80 represent mild, moderate, severe and extremely severe fatigue respectively. The results showed the general fatigue condition of controllers: 1 % no fatigue, 18 % mild fatigue, 58 % moderate fatigue, 19 % severe fatigue, and 4 % extremely severe fatigue.

The survey consisted of four different dimensions: general fatigue, physical fatigue and mental fatigue, and reduced motivation. The statistical results are shown in Table 3: 55 % controllers reported they had severe fatigue and above; 30 % of the controllers considered themselves serious physical fatigue and above; 46 % of the controllers considered themselves serious mental fatigue and above; 38 % of the controllers indicated they had reduced motivation.

Results showed that 58 % of the controllers at a moderate level of fatigue. Additionally, 23 % of the controllers had reached the extent of severe fatigue and above, especially in two aspects: mental fatigue and reduced motivation. Therefore, the mental workload and reduced motivation were identified as the two most serious fatigue dimensions.

Table 3. Distribution of different dimensions of fatigue

Fatigue / Four dimensions	No fatigue	Light fatigue	Moderate fatigue	Severe fatigue	Extreme fatigue
General fatigue	3%	10%	32%	32%	23%
Physical fatigue	4%	16%	34%	20%	10%
Mental fatigue	4%	16%	42%	32%	14%
Reduced motivation	14%	22%	34%	25%	13%

3.2 Controllers' Fatigue by Different Operational Positions

The results of controllers' fatigue conditions with different positions are shown in Table 4. In general, fatigue of the controllers working at four different positions was rated as moderate. Physical fatigue scores were lower than mental fatigue scores, which indicated that controllers have higher mental pressure. This may because most of the time the controllers were doing their brain works. As for approach controllers, their mental fatigue scores were higher than tower controllers, area controller, and flight service controllers. This indicated that approach controllers had a higher level of mental fatigue, which may be caused by complex airspace operations and busy air traffic. Flight service controllers had less working motivation than others. This may be because flight service controllers 24 h work shifts led to a lack of job interests.

Table 4. The fatigue status of controllers from different positions

Positions	Total points	General fatigue	Physical fatigue	Mental fatigue	Reduced motivation
Tower controllers	49.0 ± 5.3	13.1 ± 2.0	11.6 ± 1.4	13.9 ± 2.1	13.1 ± 2.6
Approach controllers	50.1 ± 4.7	13.3 ± 1.8	11.2 ± 1.7	15.6 ± 1.7	13.9 ± 2.2
Area controllers	50.5 ± 4.9	12.9 ± 2.3	11.6 ± 2.3	12.9 ± 2.3	13.9 ± 2.4
Flight service controllers	50.7 ± 4.3	12.5 ± 1.9	11.4 ± 1.5	11.1 ± 1.4	14.5 ± 2.9

3.3 Analysis of Controllers Sleeping

Analysis of Controllers Sleep Quality. Survey results showed that the general condition of controllers' sleep quality was good. Only 10 % of the controllers was assessed their sleep quality as very poor. Nearly half of the controllers slept 6–7 h each day. 67 % of the controllers' sleep efficiency was greater than 85 %, and 9 % of the controllers' sleep efficiency was below 74 %. 56 % of the controllers had long sleep latency factors, which may indicate that controllers needed a long time to fall asleep.

Table 5. Correlation analysis between sleep quality and fatigue

Four dimensions	Sleep quality correlation index	Sig
General fatigue	0.51	<0.01
Physical fatigue	0.27	<0.05
Mental fatigue	0.60	<0.01
Reduced motivation	0.05	>0.05

Correlation analyses of sleep quality and four dimensions of fatigue were conducted (results shown in Table 5). With a 99 % confidence level, controllers' general fatigue was related to sleep quality. In addition, sleep quality had a strong relationship with mental fatigue. In 95 % confidence level, sleep quality had weaker correlation with physical fatigue, but it had no relation with reduced motivation.

Sleep Factor Analysis of Different Fatigue Level. The researchers analyzed seven sleep factors for the controllers with high level of fatigue and low level of fatigue (results are shown in Table 5). According to factor analysis, the most prominent problem affecting sleep quality was sleep latency. Controllers cannot easily fall asleep in a short time, which may be related to controllers' long time night shifts. Controllers with high level of fatigue generally were accompanied with short sleeping time, usually between 5 and 7 h. Controllers with high level of fatigue were less efficient in sleeping, while controllers with light fatigue had higher efficient sleep quality. This indicated that sleep efficiency impacted on controller fatigue. The influence of sleep disorders among the controllers groups was not obvious. High-fatigued controllers' daytime dysfunction received higher scores (Table 6).

Table 6. A comparison of sleeping quality factors of different fatigue levels

Sleep quality factors	Subjective sleep quality	Sleep latency	Sleep time (h)	Sleep efficiency	Sleep disorders	Using sleep medicine	Daytime dysfunction	Total scores
All controllers	1.9 ± 0.8	1.7 ± 0.9	6.4 ± 1.0	0.6 ± 0.9	1.4 ± 0.6	0.3 ± 0.6	1.8 ± 0.7	8.3 ± 3.2
Light fatigue controllers	1.7 ± 0.8	1.6 ± 0.9	6.5 ± 0.9	0.5 ± 0.9	1.4 ± 0.6	0.2 ± 0.5	1.7 ± 0.7	7.7 ± 3.1
High fatigue controller	2.6 ± 0.7	2.2 ± 0.8	6.0 ± 1.1	1.2 ± 1.0	1.5 ± 0.5	0.5 ± 1.0	2.2 ± 0.7	11.2 ± 2.6

Sleep and Fatigue Analysis of Different Positions. Considering fatigue differences between different positions, the researchers analyzed sleeping factors of controllers with different positions. As shown in Table 7, generally the controllers with different positions showed a similar sleep condition.

3.4 Analysis of Controllers' Work-Related Factors

The self-assessment of workload results are showed as Table 8. The majority of the controllers reported they had a moderate level of workload. 60 % of approach

Table 7. Sleep condition contrast for different position controllers

Position	Total points	Subjective sleep quality	Sleep disorders	Daytime dysfunction	Sleep time
Tower controllers	8.7 ± 3.7	1.9 ± 0.8	1.6 ± 0.5	1.6 ± 0.7	6.4 ± 1.1
Approach controllers	8.1 ± 3.0	2.0 ± 0.7	1.3 ± 0.6	1.7 ± 0.9	6.5 ± 0.8
Area controllers	8.4 ± 4.0	1.8 ± 0.8	1.4 ± 0.6	1.6 ± 0.8	6.5 ± 1.1
Flight service controllers	8.1 ± 2.5	1.6 ± 0.8	1.2 ± 0.4	1.6 ± 0.9	6.5 ± 0.9

controllers suffered from high workload. Through on-site investigation, the researchers found that the ATC facility had a serious approach controller shortage. Executive controller continuously working for two hours would not have a break time, and just moved to coordinating positions to work. In most cases a coordinated controller was working with two executive controllers at the same time.

Table 8. Workload of controllers

	Low workload	Moderate workload	High workload
Tower controllers	0 %	67 %	33 %
Approach controllers	0 %	40 %	60 %
Area controllers	0 %	71 %	29 %
Flight service controllers	0 %	82 %	18 %

The researchers analyzed the on-duty rest of controllers with different positions. The results (Table 9) indicated that 75 % of the tower controllers after 2 h work did not have enough rest, while 25 % of them had enough rest. Similarly, 71 % of the approach controllers surveyed reported that they had no enough rest; By contrast 29 % had enough rest. Additionally, 56 % of the area controllers felt they had enough rest, while 44 % provided a negative answer.

Table 9. Rest of controllers

	Enough rest	Fatigue	Not enough rest	Fatigue
Tower controllers	25 %	49.2 ± 5.4	75 %	58.2 ± 4.7
Approach controllers	29 %	50.7 ± 3.7	71 %	67.7 ± 3.9
Area controllers	44 %	50.1 ± 4.2	56 %	54.1 ± 5.3

Survey of factors pertaining high workload demonstrated that weather and military restrictions were two main factors contributing to high workload (as shown in

Table 10). Other major factors were spatial complexity, and internal and external communication.

The results also showed that the majority of controllers mentioned ATC equipment performance had a significant impact on controllers' workload (as shown in Table 11), especially in terms of equipment stability and accuracy.

Table 10. Factors leading to high workload

	Military restrictions	Spatial complexity	Weather	Internal and external communication	Exception handing	Taking new controllers	Others
Ratio	21 %	16 %	23 %	16 %	15 %	7 %	2 %

3.5 Analysis of Life Event Impacts

Table 11. Equipment performance impact on controller

Influence level	1	2	3	4	5
Proportion	15.8 %	28.9 %	28.9 %	15.8 %	10.5 %

In order to understand how life events impacted controllers' fatigue, the Life Change Units (LCU) was included in the survey. Correlation and regression analyses among variables were analyzed by using SPSS 22.0. Pearson correlation coefficient between life events and fatigue was 0.64 ($P < 0.01$).

Regression analysis between fatigue and life events is showed in Table 12.

Table 12. Regression analysis between fatigue and life events

	Beta	R^2	F
Life events	0.64^{**}	0.42^{*}	55.36^{*}

Goodness of fit R^2 was high (0.42), which showed a linear relationship between fatigue and life events. Fitting equation can be concluded as:

$$Y = 1.020X + 9.794 \quad (1)$$

Regression analysis between high fatigue and life events is as shown in Table 13. R^2 was 0.54, which indicated a close relationship between life events and high fatigue in high-fatigued controllers. Controllers with high life events scores usually suffered from a high level of fatigue.

Table 13. Regression analysis between high fatigue and life events

	Beta	R^2	F
Life events	0.73^{**}	0.54	17.76^{**}

3.6 Analysis of Controllers Personality and Fatigue

In this section, controllers with high fatigue scores and low fatigue scores were selected for data analysis (results are as shown in Table 14). Personality scores of controllers with mild fatigue were higher than those controllers with high level of fatigue, especially in terms of extraversion, agreeableness and openness. This indicated controllers who tend to be extroverted, be good at interacting with people and learning new things may suffered less from fatigue.

Table 14. Personality scores for controllers of different fatigue levels

	Extraversion	Agreeableness	Conscientiousness	Neuroticism	Openness
All controllers	24.2 ± 1.8	18.9 ± 1.9	22.1 ± 1.9	19.0 ± 1.9	20.3 ± 2.8
Light fatigue controllers	26.3 ± 2.1	20.7 ± 2.4	21.3 ± 2.3	20.2 ± 2.4	22.6 ± 2.6
High fatigue controllers	16.3 ± 1.7	15.4 ± 1.8	18.2 ± 1.8	16.7 ± 2.0	14.9 ± 2.5

Table 15. T test about extraversion scores between mild fatigue and high fatigue controllers

		Levene's Test for Equality of Variances		T-test for Equality of Means					
		F	Sig.	t	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95 % Confidence Interval of the Difference	
								Lower	Upper
Personality scores	Equal variances assumed	4.114	0.009	2.080	0.015	2.723	1.310	0.000	5.447
	Equal variances not assumed			2.731	0.013	2.723	0.997	0.649	4.798

In order to verify the relationship between personality and fatigue, a T test was applied in data analysis. The results showed extraversion scores of mild fatigue controllers had a significant difference with high fatigue controllers. The F value (4.114) for extraversion scores was calculated in a 95 % confidence level (as shown in Table 15). The variance of extraversion scores between mild fatigue and high fatigue existed significant differences. The results of T tests shown that the probability of the t-value was 0.013. The hypothesis was rejected indicating that there was a significant difference between light fatigue and high fatigue.

The same method was applied for agreeableness, conscientiousness, neuroticism and openness scores. Results showed that agreeableness and openness between mild fatigue controllers and high fatigue controllers exist significant differences. However, there are no significant differences in conscientiousness and neuroticism.

4 Conclusion

The researchers of this study utilized a survey to understand air traffic controllers' fatigue in China. Six components were included in the survey, they are: personal information, subjective assessment of fatigue, workload-related factors investigation, sleep quality, life event impacts, and personality. The survey was carried out in an air traffic control facility in China. The researchers also analyzed the reliability and validity of the survey. The researchers found that sleep quality, working factors and daily life factors were contributed for fatigue of air traffic controllers surveyed.

On-site survey seems obtain a cheerful ending. However, our work mainly analyzed the feelings of fatigue with other factors. Hopefully further in-depth analysis and more surveys in China are expected to make this study perfect.

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