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Fatigue in air traffic controller: The work-related factors

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Abstract. Air traffic controllers need constant vigilance to properly monitor the speed, position, and altitude of aircraft. Subsequently, due to the high risk, officers do not need to experience excessive fatigue during working hours. Therefore this study aims to determine the work-related factors responsible for fatigue in air traffic controllers. The fatigue was measured by self-rating before and after one shift included mental fatigue and drowsiness using the Samn-Perelli scale, Karolinska sleepiness ccale (KSS), and visual fatigue scale. Furthermore, this study also analyzed the work-related factors, namely work units, workload, shift, and workdays. The results showed that shifts significantly differentiated the fatigue of the three scales, especially at night compared to morning and day. Meanwhile, the difference in mental workload only distinguishes the value of visual fatigue. In conclusion, the working conditions of air traffic controllers causes fatigue, therefore, air traffic service management needs to use these findings to set work schedules.

Keywords: mental fatigue, sleepiness, visual fatigue, air traffic controller

1. Introduction

Air Traffic Controllers (ATCo) are assigned to monitor the speed, position and altitude of aircraft prevent collisions. Their primary duties are primarily to regulate air traffic and provide information and support for pilots from control towers [1]. Therefore, continuous vigilance is needed [2] to ensure that all aircraft within their jurisdiction are adequately separated and can reach their destination safely in accordance with the rules of the international civil aviation organization (ICAO) [3]. The demands related to the complexity of air traffic conditions, space, and operations [4] cause mental workload on these officers, and when this condition is prolonged, it leads to fatigue.

According to [5], fatigue in air traffic controllers can increase errors and decrease cognitive and overall performance, thereby causing fatal consequences such as Breakdown of Separation (BoS) or even accidents. ATCo is directly or indirectly responsible for approximately 3-5% of airplane accidents [6] because they constantly interact with pilots from the control tower. Therefore, it is important to create appropriate strategies to detect or monitor fatigue conditions.

Air traffic control is conducted 24 hours, therefore, care is needed in scheduling work-time and allocating human resources to avoid excessive fatigue. Currently, these officers make use of a rotational working-time schedule system, which allows them to work in the morning #1 (06.00-12.00), followed by another morning shift #2 (08.00-14.00) in the next day, and subsequently ends with a noon shift#1 (12.00 – 18.00) in the following day, before a two day off. After having days off; the ATCo will work again in shift noon #2, and so on.This rotational shift results in workers working along with their circadian rhythms. Officers are not allowed to work for consecutively for

6 hours on a particular day, therefore, after working for 2 hours, they are allowed to have some 2 hours to rest before continuing their duties for the next 2 hours. In addition, after completing the second working time slot, there is every possibility that the officer is asked to go home.

The scheduling at ATCo is made to ensure officers have sufficient time to rest, socialize, and recover from fatigue. However, air traffic control (ATCo) requires full concentration and vigilance throughout its working time without allowing for error (zero tolerance). Therefore, irrespective of the work schedule for ATCo, it is important to monitor the workload and fatigue level to avoid errors and incidents.

This study was carried out in 2019 before the evolution of the Covid-19 pandemic to determine the workload and fatigue conditions of ATCo officers at one of the major airports in Indonesia. The results showed that the ATC officers' experienced perceived mental load and fatigue while carrying out their duties [7]. As a continuation of our previous study, this research discusses the effect of work factors on fatigue felt by ATCos. In general, work-related and external factors are some of the causes of fatigue by ATCo officers [8]. There are several factors related to work, namely work schedule, working time, and environmental conditions [9]. This research focuses on enriching knowledge on several work-related factors that affect fatigue in ATCo. Fatigue assessment was carried out using a subjective approach by filling out the mental fatigue scale and supporting data. The results of this study can be used as input for ATCo managers in organizing work-related factors capable of causing fatigue.

2. Method and material

2.1 Data collection and apparatus

A field survey was conducted to map the fatigue condition at ATC. In addition, a survey was directly carried out on ATC officers that were on duty during certain days. The questionnaire aimed to examine the general working conditions of ATC and the factors that influence these conditions. The questionnaire results were used to determine important factors that are considered in designing experiments related to workload and fatigue at ATC. The research was conducted on days and months when air traffic conditions were normal, excluding holidays to determine the conditions of workload and fatigue in traffic conditions that are not too dense, while exceeding normal conditions.

The questionnaire was used to assess the value of perceived workload and fatigue during each working-time. In addition, the ATCos had to fill the questionnaire before and after they completed the task. In each working-time, approximately 15 questionnaires were randomly distributed to ATCos in approach control office (APP) and area control center (ACC). All questionnaires were ensured have been filled out completely and following the outline guidelines before they were submitted. During the data-gathering period, two hundred fifty-six questionnaires were collected, which can be used for further processing.

2.2 Factors affecting fatigue in ATCo

Time and work schedules have an impact on the risk of fatigue. For example, working at night and for a prolonged period causes fatigue. Furthermore, there are several factors related to time with ATC officer scheduling, such as duration time and working days of ATCo. These were gathered by interviewing shift supervisors and internal data of the ATCo location.

a. Duration (*time on task*)

   The total working time of ATCo officers is a maximum of 4 hours per day, which is separated into two periods. For 1.5 to 2 hours (depend on the shift), ATCo officers continuously observe the ATC screen to visualize and manage aircraft traffic according to their work area and to keep

abreast of the developments. Therefore, it can be said that the entire working time duration is spent effectively.

b. Working days
   Based on internal ATCo data, the most massive traffic tends to occur on Fridays and Sundays. It also showed that on Saturdays, the number of flights is lower than weekdays. Due to the differences in the number of flights, working days also affect employee fatigue level.
c. Working-time
   ATCo officers can work in the morning (6 am to 2 pm), afternoon (2 pm to 8 pm), or evening (8 pm to 6 am). Morning working-time tends to be busier than afternoon and evening. Subsequently, the evening working-time is quite crowded compared to the afternoon because people tend to choose the morning and evening time to depart or to return from their activities. Therefore, the workload is predicted to be higher than in the evening, which means that high task demands likely cause fatigue. The biggest challenge faced by officers is the need to continuously maintain vigilance when tired which causes fatigue, due to sleepiness
d. Workload
   Focus on work, conducting repetitive or monotonous work, and carrying out work that needs sustained physical effort, can cause mental and physical fatigue [8]. Fatigue also occur in situations of overload, underload and boredom or sleepiness.

2.3 Data analysis

The mental fatigue of ATCo officers was conducted at airport X [7], using the Samn-Perelli scale [10] with a value of 1-7, used to determine their level of fatigue [3], with the interpretation used for categorization [11]. Furthermore, sleepiness assessment was carried out using the Karolinska sleepiness scale (KSS), with an absolute rating scale of 1-9 levels [12]. Meanwhile, three categories of the KSS level were used for interpretations [13]. The visual fatigue scale (VFS) was used [14] to assess the level of visual fatigue with a 10 points Likert scale to test the effect of display technology (computer screen) [14]. This scale contains six statements related to symptoms of visual fatigue, namely difficulty in seeing, strange feelings around the eyes, fatigue, numbness, headaches, and dizziness when looking at the screen. Mental fatigue, sleepiness, and visual were assessed at the beginning and end of each working-time. Previous research [7] showed a significant increase in the value of fatigue before and after work, which is at a reasonable level. However, the factors affecting the workload or fatigue have not been discussed.

For every work-related factor, the two independent t-test samples were used to test the varying mean in fatigue difference (before and after work) between two samples. So, tested variables is the fatigue score difference, not the fatigue score. When the factors have more than two categories, then the t-test was carried out several times for each pair. For instance, in the factor with three categories of a, b, and c, the t-tests were conducted 3 times, for a-b, a-c, and b-c.

3. Result and discussion

Several work-related factors contribute to fatigue. In this survey, the work-related time factors discussed are working-time, working days, work section, and perceived workload.

3.1. Correlation between working-time and fatigue

Generally, there are three working-times, namely morning (6 am to 2 pm), afternoon (2 pm to 8 pm), and evening (8 pm to 6 am). The analysis of two samples, independent t-test, was used to determine whether working-time differ the fatigue score difference (before and after work), as

shown in **Table 1**. The table shows that there are differences in the average increase in the level of mental fatigue, sleepiness, and visual fatigue felt by ATCo officers due to the variations in working-time, especially at night. At night, although airplane traffic tends to be small compared to the morning, it turns out that the fatigue felt by officers tends to be higher than during other working-times. This happens because, at night, the officers are fatigue due to previous activities and sleepiness.

Table 1. Two samples of independent t-test based on working-time and fatigue value differences

Working-time	Sample count	Mental Fatigue		Sleepiness		Visual Fatigue	
		Mean	Variance	Mean	Variance	Mean	Variance
Morning	128	1.664	1.044	1.75	3.181	0.958	1.953
Afternoon	104	1.683	1.908	2.01	3.514	1.263	3.384
Evening	25	2.400	1.500	3.24	2.857	2.120	3.182
Comparison		P value	T value	P value	T value	P value	T value
Evening – Morning		0.008**	2.673	0.000**	3.688	0.004**	2.891
Evening – Afternoon		0.014*	2.485	0.003**	3.034	0.038*	2.091
Afternoon – Evening		0.909	0.114	0.267	1.112	0.165	1.394

3.2 Correlation between days and fatigue

Table 2. Two samples of independent t-test based on days and fatigue value

Day	Sample count	Mental Fatigue		Sleepiness		Visual Fatigue	
		Mean	Variance	Mean	Variance	Mean	Variance
Thursday	94	1.851	1.698	2.074	4.392	1.339	2.503
Friday	60	1.75	1.174	2.250	2.699	1.142	1.521
Saturday	103	1.641	1.448	1.796	2.987	1.092	3.689
Comparison		P value	T value	P value	T value	P value	T value
Thursday – Friday		0.603	0.521	0.563	0.580	0.387	0.867
Thursday – Saturday		0.242	1.173	0.313	1.011	0.323	0.990
Friday – Saturday		0.552	0.595	0.098	1.666	0.841	0.201

Data were collected for three days, namely Thursday, Friday, and Saturday, which represent weekdays and weekends. Furthermore, the internal ATC data collection showed that air traffic on Fridays tends to be higher than Thursdays and Saturdays. Thursday represents the average number of flights per day, while Saturday has a relatively lower number of flights than other days. Based on the two independent samples t-test, it can be concluded that day is not a differentiating factor for the increase in fatigue felt by officers. **Table 2** shows that the average increase in mental fatigue, sleepiness, and visual fatigue felt is in the range of 1 and 2 points for all days. Therefore, an increase in traffic flow on a given day does not change the rise in fatigue level of officers. This occurs because there are similarities in aircraft traffic during the time of data collection.

3.3 Correlation between work unit and fatigue

Due to the difference in the assigned tasks, work units may cause differences in increased fatigue. Hoeever, using the two independent samples of t-test, the differences between the APP and ACC

work units failed to differ in the average increase in mental fatigue, sleepiness, and visual fatigue. **Table 3** shows that the average increase in mental fatigue and perceived sleepiness is between 1 and 2 points, in the APP and ACC units. However, this process was insignificant, with the increase in fatigue levels felt more by ACC officers than APP.

Table 3. Two samples of independent t-test based on work section (ACC/APP) and fatigue value

Item	Sample count	Mental Fatigue		Sleepiness		Visual Fatigue	
		Mean	Variance	Mean	Variance	Mean	Variance
ACC	138	1.819	1.522	2.116	3.402	1.433	3.365
APP	110	1.628	1.429	1.873	3.617	0.846	1.466
Comparison		P value	T value	P value	T value	P value	T value
ACC – APP		0.909	0.114	0.267	1.112	0.165	1.394

3.4 Correlation between mental load category and fatigue

In our previous research, the mental load felt by officers is classified into moderate, high, and very high categories [7]. Furthermore, based on the two independent samples t-test, it was concluded that the difference in mental load, significantly differentiated the mean visual fatigue, especially between the moderate, high, and very high categories as shown in **Table 4**.

Table 4. Two samples of independent t-test based on mental load category (moderate, high, very high) and mental value

Mental load	Sample count	Mental Fatigue		Sleepiness		Visual Fatigue	
		Mean	Variance	Mean	Variance	Mean	Variance
Moderate	34	1.676	1.389	2.088	2.750	0.657	0.845
High	102	1.765	0.913	2.010	3.653	1.221	2.082
Very High	121	1.793	1.715	1.975	3.508	1.310	3.690
Comparison		P value	T value	P value	T value	P value	T value
Moderate – High		0.662	0.438	0.819	0.229	0.010*	2.631
Moderate – Very High		0.778	0.282	0.855	0.183	0.010*	2.599
High – Very High		0.393	0.856	0.949	0.064	0.773	0.288

However, when analyzed further, the mental fatigue increased with a rise in mental load, although the difference was insignificant. On the other hand, sleepiness showed a different pattern as it tends to decrease with an increase in mental load. Therefore, this research is in line with previous studies which stated that lower mental load causes more sleepiness [16].

3.5 Next research

The next stage of this research is developing a fatigue monitoring system for the high mental workload. The survey to real ATC system was carried out to analyze the perceived fatigue and workload conditions due to the daily load of ATCo. Furthermore, the experimental approach with simulators was used to eliminate the risk of errors and fatalities compared to observations made in the actual work environment. Meanwhile, the correlation between work-related factors with mental fatigue, sleepiness, and visual fatigue scores are summarized in **Table 5**. These factors are considered when planning the experiment.

Based on the field study, it was confirmed that the ATCo experience fatigue. Subsequently, experiments were designed to stimulate fatigue conditions by considering the factors that influence workload. The working-time was proven to be related to mental load, sleepiness, and visual fatigue. Meanwhile, the increase in perceived mental load was related only to visual fatigue value. Therefore, these factors were determined to minimize the diversity of cognitive abilities.

Table 5. Summary of correlation between working factors and difference of fatigue

Factors	Mental Fatigue	Sleepiness	Visual Fatigue	Remarks
Working time	X	x	x	Night shift has higher scores compared to others
Working day	-	-	-	This factor did not differ fatigue significantly
Work unit	-	-	-	This factor did not differ fatigue significantly
Perceived mental load	-	-	x	Fatigue tends to be higher with the increase in mental load, but only significant in visual fatigue score

4. Conclusion

In conclusion, ATCo officers' experience a significant increase in fatigue scores, even though its value was still within reasonable limits. The increase in mental fatigue, sleepiness, and visual fatigue felt by ATCo officers varied based on working-time. For instance, the fatigue felt by officers tends to be higher at night than other times of the day. It probably because, during the night, the officers are mandated to carry out their activities and endure sleepiness at the same time. Meanwhile, the difference in mental load was significantly differentiated by the mean in visual fatigue, especially between the moderate to high and very high categories. However, further analysis showed that mental fatigue increases with a rise in mental load, although the difference is insignificant. This is different in sleepiness, which shows the opposite pattern by decreasing with an increase in mental load. These follow previous studies, which stated that lower mental load would lead to more sleepiness. The results of this research, which are in accordance with previous studies, is used as input to design further experiments related to the development of a fatigue monitoring system in jobs with high mental loads.

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