Exploring Air Traffic Controllers Rosters for Fatigue Risk Management

Wen-Chin Li[1], Jingyi Zhang[1], Peter Kearney[2] & Graham Braithwaite[1]

[1] Cranfield University, UK; [2] Irish Aviation Authority, Ireland

ABSTRACT

Fatigue is an inevitable hazard in the provision of air traffic services as it has the potential to degrade human performance leading to safety occurrences, incidents or even accidents. Arranging work rosters properly could be an effective element of fatigue risk management. This research aims to investigate air traffic controllers' sleepiness levels and the impact of the current roster matrix on fatigue. Fifty-seven qualified air traffic controllers participated in the current study. The results demonstrated that the compressed nature of the roster between shift-4 and shift-5 increased sleepiness levels by reducing preceding sleeping hours and accumulating circadian dysrhythmia. Furthermore, the last three hours (6th hour, 7th hour, and 8th hour) on the working position presented high fatigue levels due to the depletion of controllers' mental and physical resources. Therefore, it is suggested that breaks should be taken between the 6th and 7th working hour to prevent controller from "burning out", and switch shift-1 to shift-5 to mitigate the impacts of circadian dysrhythmia.

KEYWORDS

Air Traffic Services, Fatigue Risk Management, Shift Works, Sleep deprivation, Circadian Rhythm,

Introduction

Fatigue has complicated mental and physical contributing factors that can include insufficient sleep, circadian dysrhythmia, perceived workload, extended duty periods, clinical sleep pathology, psychosocial aspects, environmental factors, and roster matrix. It has a negative impact on human performance and can lead to output deficits and safety lapses (Gaydos, Curry, & Bushby, 2013; Huey & Wickens, 1993). Fatigue can impair a variety of psychomotor skills and cognitive functions that are critical for human performance in aviation (Caldwell et al., 2009) and other high consequence industries (Paltrinieri, Dechy, Salzano, Wardman, & Cozzani, 2012). Therefore, strategies to mitigate the effects of fatigue are primarily centred on regulatory and scientific approaches which limit working hours to prevent chronically sleepy individuals working in the fields of aviation, medical care and manufacturing industries (Balkin, Horrey, Graeber, Czeisler, & Dinges, 2011).

Fatigue is a hazard which can reduce the task performance of an air traffic controller (ATCO) in monitoring and controlling a dynamic environment with crossing, climbing and descending aircraft.

Fatigue can contribute to aviation accidents/incidents as a fatigued ATCO may make inappropriate decisions that put pilots and passengers at increased risk (Kearney, Li & Braithwaite, 2019). Fatigue Risk Management Systems (FRMS) have been introduced in the context of the evolution of pilots' performance-based regulations by the International Civil Aviation Organization in the 1990s (ICAO, 2018). The Fatigue Safety Action Group (FSAG) of the International Air Transport Association (IATA) has reviewed and identified fatigue hazards in flight operations including subjective alertness assessment and fatigue reporting metrics (IATA, 2014). However, while there are many FRMS for airline pilots, FRMS for air traffic controllers are comparatively rare. There is a growing need to develop FRMS to optimize ATCOs' performance and increase ATCOs' wellbeing. The requirement for ANSPs (Air Navigation Services Providers) to implement fatigue risk management systems is scheduled to take effect from November 2020 and will be contained in ICAO Annex 11 (International Standards and Recommended Practices for Air Traffic Management). It requires ANSPs to implement fatigue risk management policies and strategies in order to mitigate ATCOs' fatigue (ICAO, 2018).

Method

Participants

Fifty-seven qualified ATCOs from a European Air Navigation Services provider participated in this research. The ages of participants were between 23 and 58 years (M = 41.18, SD = 6.52), and their working experiences varied from 1 to 38 years (M = 17.00, SD = 8.10) as certified air traffic controllers. The approval of the University Research Ethics Committee was granted (CURES/2470/2017) in advance of the research taking place. All participants were informed that the research was related to ATCOs' shift work and fatigue management. Participants were guaranteed the right to withdraw from the research at any stage. All collected data is only available to the research team and stored in accordance with the United Kingdom Ethical Code and the Data Protection Act.

Material

The material used in this study is based on the Stanford Sleepiness Scale (SSS) which was developed by Hoddes, Dement and Zarcone (1972) to evaluate the subjective sleepiness levels in real world operations, and has been validated for general populations. SSS is a one-item self-report form to track overall alertness at each hour of the day. This research adapted the SSS to evaluate one-item (alertness level) pre-shift, on-shift and post-shift by scoring ranges from 1 for the highest alertness to 7 for sleep onset soon, except the hours of sleep. The participants were invited individually to a briefing on how to use the sleepiness rating scale over the course of their Shift pattern. ATCOs had to rate their own sleepiness levels for each hour both working (W) and resting (R) using 7-point Likert scales. Furthermore, ATCOs were encouraged to add their comments to the roster and FRMS at the end of the evaluation form.

Procedures

The current ATC roster requires air traffic controllers to work a designated period of five consecutive working days, followed by three rest days (Fig. 1). This research applies a self-reporting technique whereby ATCOs recorded their own fatigue levels hourly without interference from the experimenters. The strength of this self-report diary is that it enables participants to express their feelings and thoughts. However, the weakness is that gathering information about thoughts or feelings is only useful if participants are willing to disclose them to the experimenter. There are 13.5 hours available to recover from fatigue before the first shift, 17 hours of interval to recover from fatigue before the second shift, 9.25 hours to recover from fatigue before the third shift, 14.5 hours to recover from fatigue before the fourth shift, and 9 hours to recover from fatigue before the fifth shift. Understanding the relationship between fatigue levels and preceding sleeping hours is critical for developing FRMS.

Results

Sample Characteristics

ATCOs' fatigue indicators can be separated into seven levels from the lowest sleepiness level-1 to the highest sleepiness level-7. ATCOs on the working position reflect the day-to-day and hour-to-hour fatigue levels of real-world operations. The homogeneity of variances was verified using Levene's test, and post-hoc pairwise comparisons were performed by Bonferroni. Effect sizes of samples were quantified by partial eta square (η_p^2). The descriptive statistical data of ATCOs' fatigue levels over eight working hours per day among five consecutive shifts are shown as Table 1.

Table 1: Participants' means and standard deviations of fatigue among eight working hours on five consecutive shifts

Fatigue level	N	Shift-1		Shift-2		Shift-3		Shift-4		Shift-5		Hourly average	
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
1st hour	57	1.55	0.70	1.42	0.64	1.69	0.80	1.86	1.06	1.77	0.79	1.66	0.07
2nd hour	57	1.55	0.70	1.37	0.53	1.67	0.89	1.69	0.98	1.92	1.02	1.64	0.07
3rd hour	57	1.36	0.56	1.53	0.66	1.70	0.82	1.78	0.92	2.33	1.24	1.74	0.08
4th hour	57	1.41	0.58	1.48	0.68	1.44	0.70	1.76	0.91	2.41	1.22	1.70	0.08
5th hour	57	1.45	0.62	1.52	0.75	1.48	0.73	1.66	0.83	2.33	1.48	1.69	0.09
6th hour	57	1.73	0.68	1.65	0.85	1.65	0.89	1.67	0.87	2.48	1.42	1.84	0.10
7th hour	57	2.31	1.04	1.78	0.86	1.70	0.92	2.00	0.95	2.62	1.34	2.08	0.10

8th hour	57	2.00	0.91	1.94	0.91	1.69	0.80	2.43	0.94	3.16	1.31	2.29	0.10
Daily average	57	1.67	0.53	1.59	0.56	1.65	0.67	1.86	0.75	2.38	1.03	1.66	0.07

Roster Impact on ATCOs' Fatigue Levels

There are significant differences in ATCOs' fatigue levels among five consecutive shifts, F (4, 224) = 26.35, p < .001, η_p^2 = 0.32. Furthermore, Post-hoc pairwise Bonferroni comparison revealed that ATCOs accumulated the

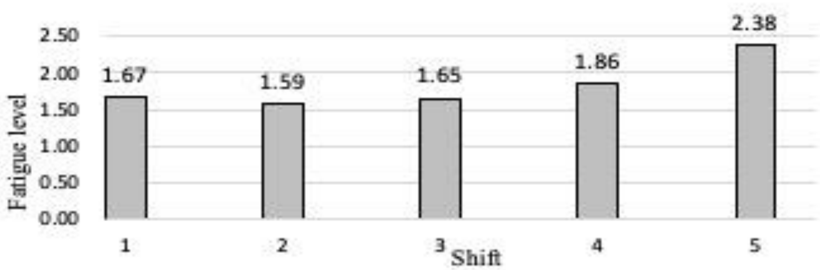

Figure 1: ATCOs' average fatigue levels among five shifts

highest fatigue level on the fifth shift (M=2.38, SD=1.03), significantly higher (p < .001) than the other four working days (Figure 1 & Table 1).

ATCOs' Fatigue Levels among Eight Working Hours on Five Shifts

ATCOs' working hours on the first day of shift are between 13:30-21:30. There are significant differences in ATCOs' fatigue level among eight working hours, F (7, 392) = 20.70, p < .001, η_p^2 = 0.27. Furthermore, post-hoc Bonferroni showed that the highest fatigue level is in the seventh hour (M = 2.31, SD = 1.04), and the lowest fatigue level is in the third hour (M = 1.36, SD = 0.56) (Figure 2 & Table 1).

ATCOs' working hours on the second day of shift are between 14:30-22:30. The results indicated significant differences in ATCO's fatigue levels among eight working hours, F (7, 392) = 7.60, p < .001, η_p^2 = 0.12. Furthermore, post-hoc Bonferroni showed that the highest fatigue level is in the last working hour (M = 1.94, SD = 0.91) and the lowest is in the second hour (M = 1.37, SD = 0.53).

ATCOs' working hours on the third day of shift are between 07:45-16:00. There are significant differences in participants' fatigue levels among eight working hours, F (7, 392) = 3.98, p < .001, η_p^2 = 0.07. Furthermore, post-hoc Bonferroni showed that the highest fatigue level is in the eighth working hour (M = 1.91, SD = 0.97) and the lowest is in the fourth hour (M = 1.44, SD = 0.70).

ATCOs' working hours on the fourth day of shift are between 06:30-13:30. There are significant differences in participants' fatigue levels among eight working hours, F (7, 392) = 11.08, p < .001, η_p^2 = 0.17. Furthermore, post-hoc Bonferroni showed that the highest fatigue level is in the eighth (12:30-13:30) working hour (M = 2.43, SD = 0.94) and the lowest is in the fifth hour (M = 1.65, SD = 0.83). ATCOs' fatigue levels are fluctuating but rising up gradually in general (Figure 2 & Table 1).

ATCOs' working hours on the last day of shift are between 22:30-06:30. There are significant differences in ATCOs' fatigue levels among eight working hours, $F (7, 392) = 18.23$, $p < .001$, $\eta_p^2 = 0.25$. According to Bonferroni, when ATCOs first started working, their fatigue level was the lowest (M = 1.77, SD = 0.79), and reached the highest (M = 3.16, SD = 1.31) in the last hour (05:30-06:30) which may be evidence of the depletion of physical and mental resources (Figure 2 & Table 1).

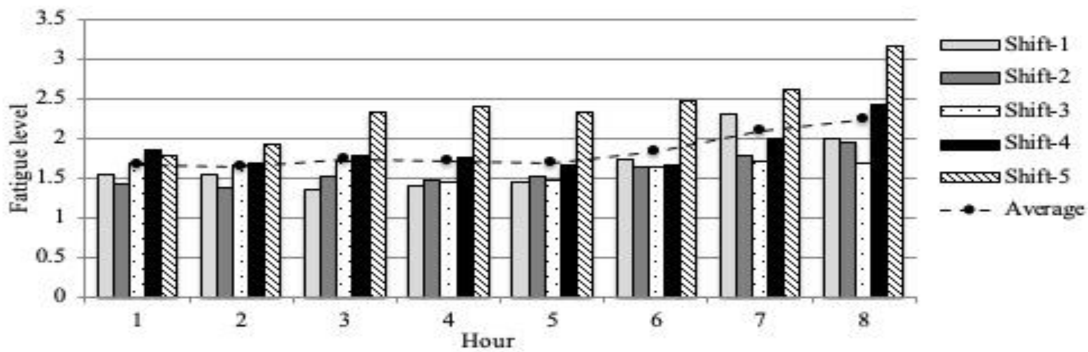

Figure 2: The fluctuation of ATCO's average fatigue level during eight working hours on five shifts

Discussion

Shift work is an effective way to ensure the performance of 24/7 ATC tasks and minimise human resource cost. However, it also has negative influences on health and can impact occupational safety (Fricke-Ernst, Kluge & Kötteritzsch, 2011). The findings of the present study indicate that ATCO fatigue levels are varied and gradually accumulate hour-by-hour and day-by-day (Table 1). It could be attributed to the arrangement of the ATCOs' roster. ATCOs' working hours over the five-shift roster are quite irregular. On the first two days, ATCOs work from afternoon to evening. Then in the third and fourth days, they must start from early morning to afternoon. On the fifth day, it is a core night duty with only nine hours preceding rest (Figure 2). ATCO shift work against circadian rhythm resulted in a circadian dysrhythmia, which can lead the bodies' internal rhythms to being out of synchrony with the day-night cycle. This can be a significant factor impairing monitoring performance (Tirilly, 2004). It is not surprising that night workers often perform poorer than daytime workers due to a lower body temperature and disturbed circadian rhythm. The drive for sleep also varies on a 24-hour cycle under the influence of the circadian biological clock, which also dictates the preference for sleep at night (Signal et al., 2003). Previous research has also indicated that subjective fatigue varied in parallel with the circadian biological clock and sleep-wake cycle (Baek & Choi-Kwon, 2017; Mulhall et al., 2019), time-on-task and time of day (ICAO, 2016). ATCOs generally have a higher fatigue level during the late night and early morning. ATCOs must perform monitoring tasks and provide air traffic services over a 24-hours basis, which could bring high work pressure and circadian disorder.

Also, shift work could lead to increased difficulty in obtaining recovery sleep during rest days (Kandelaars, Fletcher, Eitzen, Roach, & Dawson, 2006). The daily quantity of sleep required varies individually, but on average it is eight hours (Van Dongen, Maislin, & Dinges, 2004). The available sleeping hours in these nine hour intervals between shift-4 and shift-5 has to take into account commuting time, showering, eating and relaxing before getting sleep. Therefore, the average sleeping hours preceding the fifth shift is only 4.88 hours on average which is much less than the baseline of 8 sleeping hours daily. This is the reason the fatigue level is the highest in the fifth shift (Figure 2 & Table 1). ATCOs did mention that when they finished the night duty it can be a struggle to get to sleep during the first rest day. Some older staff members expressed their concerns regarding experiences of sleep loss, distraction while driving and nodding off at home while watching TV in the afternoon or late evening. However, this tight arrangement of rest time between shift-4 and shift-5 is as a result of ATCOs themselves who want to have an additional rest day before the next work cycle. Basically, there are three rest days following five shifts in a complete work roster. ATCOs preferred to shorten the rest hours after shift-4 and start shift-5 as early as possible (at midnight on shift-4), so that they can have a break for almost four consecutive days.

Fatigue risk management systems need to extend beyond the analysis of roster cycles, shift work, sleeping hours, breaks, task load and circadian rhythm to also consider the overall operational environment of air traffic management. They offer a way to safely schedule air traffic controllers to provide air traffic services beyond simply complying with existing regulatory limits of duty time and rest period regulation. Previous research demonstrated that task difficulty and time pressure were considered as intrinsic cognitive loads and noted to have interactions with fatigue (Galy et al., 2012); increasing traffic volume on the peak hour corresponded to a high task demand which could increase ATCO task load and the potential for occurrences of incidents or even accidents (Eurocontrol, 2003; Moon et al., 2011; Li, et al., 2020). An effective fatigue risk management system should consider the impact of shifts worked and the effects of circadian rhythm into account when prescribing limits on hours of work and numbers of breaks during daily work. When using breaks as a fatigue countermeasure, ATCOs have suggested increasing the numbers of shorter breaks (i.e. 10-15 minutes) which can increase alertness, attention, memory and help achieve optimum performance. This finding is consistent with previous research of Autumn et al. (2016). Fatigue risk management systems should be integrated with appropriate fatigue countermeasures considering the circadian rhythm of the ATCO beyond the basic roster patterns. Therefore, it is important that science-based fatigue risk management tools are applied to protect the integrity of the system at all times.

Conclusion and Recommendation

ATCO rosters reflect the requirement to provide ATC services on a 24-hour basis. ATCOs showed a preference for compressed working days during the shift pattern in order to maximize their rest days. This study demonstrated that the roster induced differing fatigue effects on ATCOs' sleepiness between shifts (five shifts) and within shifts (eight working hours per shift). This study proposed that not only rest duration but also the time of the day should be taken into consideration to improve ATCOs' alertness and ensure ATCOs make a full recovery through sufficient sleep during their rest hours. This study proposed that timely breaks can impact positively on ATCO fatigue and alertness, and it also demonstrated that short rest periods between shifts appear to be detrimental for fatigue. This could be a vital factor when considering how to influence fatigue levels. Whether ATCOs should work fixed or revolving shifts represents a debatable case as regards to balancing individual preference and task performance. Air navigation services providers must establish fatigue risk management systems that aim to ensure ATCOs are performing at adequate levels of alertness based on scientific principles and operational experiences. These principles should consider traffic volume and circadian effects on human performance, as ATCOs can only work for a limited period of time, after that a fatigue recovery break is required. By applying scientific knowledge to rostering and scheduling of breaks; human-centred design of controller working positions; and controlling traffic volume in a sector, the effect of fatigue can be mitigated. Initial fatigue countermeasure strategies should focus on sufficient breaks and schedule optimization; secondary strategies should focus on monitoring ATCOs' task loads which may induce fatigue; and finally, fatigue risk management systems should balance costs and benefits for the air navigation services providers.

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