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A Further Exploration to Fatigue Indicator in PVT of China Air Traffic Controllers

Qiuhong Piao[1,a], Zhenling Chen[2,b], Jianping Zhang[2,c], Xiang Gao[1,d]
[1]*Civil Aviation Management Institute of China, Beijing, China*
[2]*The Second Research Institute of CAAC, Chengdu, China*
[a]*piaoqiuhong@163.com*, [b]*chenzhenling@caacsri.com*, [c]*zhangjp@caacsri.com*,
[d]*Gaoxiang928@vip.126.com*

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Abstract: Current study is aiming to find a more suitable behavioral fatigue index for Air Traffic Controllers(ATC) using PVT test and fatigue self-assessment questionnaires as tools, and gives these tests before and after ATC duty. Through PVT test and self-assessment questionnaire, this finding indicates hit rate and hit response time (the first 20% trials) of PVT can be potential fatigue index since we found first 2min hit response time of air traffic controller(ATC) after duty is significantly longer than before duty, together with the hit rate after duty is lower than before duty. 8 items in Stanford Sleepiness Scale(SSS) and Visual Analogy Scale(VAS) also show significant difference in self assessment on fatigue. ATCs think themselves are much more fatigue after duty than before duty.Besides, ATCs in regional control area show significant fatigue effect than those in terminal control area, indicating different work load in two different working areas. Those ATC work at night especially in midnight show much more significant fatigue than those work in the daytime showed by longer first 20% hit response time. In sum, hit rate and first 20% (first 2min) hit response time can be effective fatigue indexes of ATC.

1. Introduction

With the rapid development of China's civil aviation industry, the passenger flow of civil aviation is also increasing rapidly. In this case, the working pressure of China's air traffic controllers(ATC) is also increasing. The data of the British aviation safety voluntary reporting system show that 13% of the operating errors are related to human factor especially the mental fatigue[1-4]. Research found that in the past 20 years (1987-2007), 70% of civil aviation accidents were related to human error[5]. It can be seen that monitoring the fatigue of controllers is of great significance to the protection of aviation safety. The International Civil Aviation Organization (ICAO) defines the fatigue of ATC as a state in which the alertness and ability to perform safety related duties of controllers are reduced due to lack of sleep, prolonged wakefulness, biological rhythm, psychological or physiological workload and other reasons, there are also many other definitions of fatigue, all of which indicate that mental fatigue will lead lower work efficiency and performance [6-10].

There are many methods to monitor the fatigue, including biological monitoring methods such as HRV, ECG and so on [10-16]. Although the results are relatively accurate, the operation is complex and time-consuming, because the operating conditions are harsh, and it needs to be carried out in special situations or places, with high cost. Thus this kind of method is not practical in the actual work scenario. In addition, it can also be monitored by subjective evaluation scale, but this kind of scale is evaluated by ATC themselves, with strong subjectivity, and may not be able to reflect objective fatigue situation. PVT test has the advantages of simplicity and fast operation and can accurately reflect the objective fatigue level of the tested person, especially the fatigue caused by sleep deprivation, irregular biological clock, sleep disorders and other reasons, which is very suitable for monitoring the fatigue of ATC in actual work scene [17-21]. This method is based on the simplest reaction time test. Its principle is that when the human body is tired, the alertness will be reduced. Therefore, the reaction time of the alertness test (quickly respond to random stimuli) will be prolonged correspondingly, and the error rate will also rise at the same time[20, 22].If ATC does have fatigue, he will show significant differences in some indicators of PVT in pre-test and post-test, such as reaction time, hit rate and so on. If there is no significant fatigue effect, it shows that the scheduling system of ATC is reasonable and will not cause serious fatigue of controllers.

In view of the fact that the fatigue state of ATC will seriously affect the safety of aviation operation, it is of great significance to find some relatively stable, accurate and sensitive indicators for monitoring ATC fatigue, which is the object of current study. In addition, the data of current study are not collected on the simulator, but collected before and after completing the actual control task in the actual workplace without affecting the rest and working state of ATC. It is closer to the actual fatigue state of the controller's work, and has high practical value. In addition, although the international research process on the fatigue of controllers is relatively fast, the research on the PVT index of ATC is rare in China. It is of great significance to find a PVT index that is more suitable for China ATC.

2. Experimental process

2.1 Experimental process

In current study, PVT test is used to detect the fatigue level of controllers. The specific experimental process is as follows. A series of letters will appear on the screen in sequence, including a pair of letters as target letters, such as T-G. when T and G appear successively, the subject is required to press the space bar as soon as possible when the next paired target letter appears on the screen. The target letter will be informed to the controller and practiced before the experiment. The interval between the appearance of each letter is 1000ms, and it is kept for 15ms on the screen. There are 600 trials (that is, a total of 600 paired letters appear on the screen), and one experiment lasts for 10 minutes.

The psychological scales commonly used in the literature to detect fatigue include the Stanford Sleepiness Scale (SSS) and the visual analogue scale (VAS)[23-27],they were all used in current study.

This experiment requires the controllers participating in the experiment to complete above tasks and record a number of indicators before their duty which is pre-duty test. After completing the duty task, they are required to complete same test as post-duty test.

2.2 Subjects

All participants in current study come from Air Traffic Management Bureau in China, 258 person-time from terminal control area and 362 person-time from regional control area. They all

attend experiment fully informed and voluntarily after signing informed consent and all received enough compensation fee. Participants must finish the same PVT task once before and after their air traffic control duty.

According to the working hours of controllers, the duty hours in a day can be roughly divided into four shifts, from 8 a.m. to 12 a.m., from 12 a.m. to 18 a.m., from 18 a.m. to 24 a.m., and from 24 a.m. to 8 a.m. We classify the first two shifts into day shift and the last two shifts into night shift. The data of 302 day shift controllers and 318 night shift controllers were collected in this study. At the initial stage, the data that only completed the pre-duty test or the post-duty test have been screened out and 620 person time data have been retained finally.

3. Experimental results

3.1 PVT analysis results of all controllers

The repeated measurement ANOVA test was carried out on the 620 person-time of pre-duty and post-duty data, and the data differences between the pre-duty and post-duty data of the same ATC on the same shift were tested in pair. The results showed that there was a significant difference in the hit rate between the pre-duty and post-duty data. Other traditional PVT indicators, including hit response time, false alarm rate, C value, d 'value, did not show statistical differences. Considering that the test time is 10 minutes and the duration is long, which may lead to the practice effect, the data of the first 20% of the trials, that is, the first 2 minutes, are intercepted for analysis. The results showed that there was a significant difference between pre-duty and post-duty reaction time in the first 20% trials, and the post-duty reaction time was longer than the pre-duty reaction time. The repeated measurement ANOVA test results showed that the average value of post-duty hit reaction time (the first 20% trials) was longer than pre-duty, indicating fatigue effect. The specific results are shown in Table 1.

Table 1 Statistical Test Result of Fatigue Index of ATC

Indicator	time	Average time	F	p value
Hit response time (first 20% trials)(ms)	Pre-duty	421.69	5.276	0.022
	Post-duty	429.00		
Hit rate	Pre-duty	0.97	4.419	0.043
	Post-duty	0.96		

The interaction test of these two indicators was carried out to test the interaction of duty shift (before and after duty), work location (regional, terminal) and duty time (day shift and night shift), showing no significant interaction effect of these three factors.

3.2 PVT analysis results of controllers in different positions

Table 2 Statistical Test Result of Fatigue Index of ATC in Different Attended Position

position	indicator	time	average	F	p value
Regional control area	Hit rate	Pre-duty	0.97	4.210	0.042
		Post-duty	0.96		
Terminal control area	Hit response time(ms)	Pre-duty	423.33	3.912	0.049
		Post-duty	417.92		

The repeated measurement ANOVA test results of the hit rate of the regional control air traffic controller show that the hit rate after the duty is significantly lower than that before the duty, indicating significant fatigue effect. The repeated measurement ANOVA test results of the hit response time from terminal control area show that the post-duty hit response time is shorter than

that of pre-duty, indicating that there is no significant fatigue phenomenon. The specific results are shown in Table 2.

3.3 PVT analysis results of controllers at different duty hours

We group the data of all controllers according to the duty period of the controllers. The controllers who work after 8 a.m. and leave before 6 p.m. are defined as day shift controllers, those who work after 6 p.m. and those who leave before 8 a.m. are defined as night shift controllers. After analyzing the data of these two different duty hours, it is found that among the controllers on day shift, the hit response time shows a significant difference between before and after the duty. The repeated measurement ANOVA test results show that the hit response time after duty is shorter than the hit response time before duty, which means that there is no significant fatigue effect, but a more obvious practice effect. Among the controllers on night shift duty, there is a significant difference in the hit response time (the first 20% trials) before and after work. The repeated measurement ANOVA test results show the average hit response time after work is significantly longer than the average hit response time before work, showing the most obvious fatigue effect. The specific results are shown in Table 3.

Table 3 Statistical Test Result of Fatigue Index of ATC in Different Attended Time

Duty time	indicator	time	average	F	p value
Day shift	Hit response time(ms)	Pre-duty	428.75	11.309	0.001
		Post-duty	419.94		
Night shift	Hit response time (first 20% trials) (ms)	Pre-duty	420.80	6.219	0.014
		Post-duty	432.72		

3.4 Subjective fatigue questionnaire analysis results

The data analysis of Stanford Sleepiness Scale(SSS) and visual analogue scale(VAS) show that there are significant differences in the pre-test and post-test scores of all controllers, regional control area controllers, terminal control area controllers, day shift controllers and night shift controllers on all 9 items. And the trend of scoring on each item is similar. In SSS item 1, VAS item 2 (anxiety and worry), VAS item 5 (irritability), VAS item 6 (degree of nerve retardation) and VAS item 7 (sleepiness), the post-duty score is significantly higher than the pre-test score. The higher the score is, the more tired the controller's self-evaluation state is. On the four items of VAS item 1 (able to concentrate), VAS item 3 (energetic), VAS item 4 (feeling confident) and VAS item 8 (speaking willingness), the post-test score is significantly lower than the pre-test score. The lower the score is, the more tired the controller's self-evaluation is. According to the results of subjective fatigue assessment scale, controllers regard that they are more tired after work.

4. Discussion

According to the analysis results of PVT, there is a significant difference in the hit response time (the first 20% trials) and hit rate of all controllers caused by fatigue before and after work. In previous studies, it has also been found that the response time and hit rate of PVT Test can show significant fatigue effect [18]. In this study, the initial statistical test did not find a significant difference in hit response time (all trials). Considering that the test duration is 10 minutes which is long, there may be practice effect, which offsets the fatigue effect. Therefore, the average hit response time of the first 20% of trials were selected for analysis, and the results show a significant fatigue effect. It shows that the hit response time (the first 20% trials) and hit rate can be used as indicators of controller fatigue effect to a certain extent. When the controllers are divided into

regional controllers and terminal controllers according to their work locations, it is found that for regional controllers, the hit rate shows a significant fatigue effect, and the hit rate decreases after duty. In the post-duty test of the terminal controller, the average hit response time is significantly shorter than the pre-duty hit response time, indicating that there is no significant fatigue effect. This difference may be caused by the difference in workload levels between the two areas to a certain extent.

When the controllers are divided into day shift and night shift according to their duty time, the analysis results show that the controllers on day shift have a significant difference in the reaction time before and after work, but this difference shows practice effect. The reaction time after work is significantly shorter than that of pre-duty. The analysis results of night shift controllers found that the difference between pre-duty and post-duty hit response time was not significant. When the first 20% of the hit response time was intercepted for analysis, it showed a significant fatigue effect, and the post-duty response time was significantly longer than the pre-duty response time.

In general, the hit response time did not show a significant fatigue effect in the data of all controllers, but the hit response time of terminal controllers and day shift controllers showed a significant exercise effect, indicating that a long time of testing may lead to the effect of exercise effect masking the fatigue effect.

This result is more meaningful. On the one hand, it suggests that a long-time PVT testing will still lead to a certain degree of practice effect. In practical application, the time should be limited to 2 minutes, and its sensitivity to fatigue level will be higher. On the other hand, it reminds us that the workload of terminal controllers and day shift controllers may not be too heavy, which will have positive guiding significance for the arrangement of controllers' scheduling.

The hit rate of regional controllers shows a significant fatigue effect, which indicates that the workload of regional controllers is heavier than that of terminal controllers. In addition, there was no significant difference in the hit response time of night shift controllers, but there was a significant fatigue effect in the hit response time of the first 20% trials. The average hit response time (the first 20% trials) after the duty is 432.72ms, which is about 12ms longer than 420.80ms of pre-duty. It fully explains that the night shift controllers have obvious fatigue, which may be caused by workload and biological clock.

The above results show that the hit response time (the first 20% trials) and hit rate in this study can be used as effective indicators of controller fatigue. The hit response time of the whole test duration has a significant practice effect on terminal controllers and day shift controllers, while there is no significant difference between the hit response time of regional controllers and night shift controllers. A possible explanation is that the workload of regional controllers and night shift controllers is greater than that of terminal and day shift controllers, but their fatigue effect is offset by the practice effect caused by longer-term testing, therefore, there is no significant difference in this indicator. This also proves the existence of fatigue effect to a certain extent.

5. Conclusion

In conclusion, through current study, it is proved that the controllers have fatigue effect, and the hit rate and hit response time (the first 20% trials) can be used as effective indicators of fatigue. It can be used as a reference for the practical work of controller fatigue monitoring, measurement and management. This study proves that the 2-minute PVT test can reflect the fatigue state of controllers through certain indicators, which can greatly shorten the PVT test time, which is of great significance for practical application.

In addition, this study also shows the subjective measurement scale can be used as an auxiliary means of fatigue measurement and monitoring, but it cannot accurately and objectively reflect real

fatigue condition.

References

[1] Caldwell, J.A., et al., Fatigue countermeasures in aviation. Aviation Space and Environmental Medicine, 2009. 80(1): p. 29-59.
[2] Valerie, J., and Gawron, Summary of Fatigue Research for Civilian and Military Pilots. IIE Transactions on Occupational Ergonomics and Human Factors, 2016.
[3] Wang, T.C. and L.H. Chuang, Psychological and physiological fatigue variation and fatigue factors in aircraft line maintenance crews. International Journal of Industrial Ergonomics, 2014.
[4] Bendak, S. and H.S.J. Rashid, Fatigue in aviation: A systematic review of the literature. International Journal of Industrial Ergonomics, 2020. 76.
[5] Bellenkes, A.H., Contemporary issues in human factors and aviation safety. Ergonomics, 2007. 50(6): p. 963-965.
[6] Li, W.C., et al., The Analysis of Occurrences Associated with Air Traffic Volume and Air Traffic Controllers' Alertness for Fatigue Risk Management. Risk Analysis, 2020.
[7] Gander, P., H. Purnell, and G.A. Woodward, Work patterns and fatigue-related risk among junior doctors. Occupational & Environmental Medicine, 2007. 64(11): p. 733-738.
[8] Marcora, S.M., W. Staiano, and V. Manning, Mental fatigue impairs physical performance in humans. Journal of Applied Physiology, 2009. 106(3): p. 857-864.
[9] Charbonnier, S., et al., EEG index for control operators' mental fatigue monitoring using interactions between brain regions. Expert Systems with Applications An International Journal, 2016. 52(Jun.): p. 91-98.
[10] Borghini, G., et al., Measuring neurophysiological signals in aircraft pilots and car drivers for the assessment of mental workload, fatigue and drowsiness. Neurosci Biobehav Rev, 2014. 44(Sp. Iss. SI): p. 58-75.
[11] Shakouri, M., et al., Analysis of the sensitivity of heart rate variability and subjective workload measures in a driving simulator: The case of highway work zones. International Journal of Industrial Ergonomics, 2018. 66: p. 136-145.
[12] Berka, C., Levendowski, D. J., Lumicao, M. N., Yau, A., Davis, G., Zivkovic, V. T., ... & Craven, P. L. (2007). EEG correlates of task engagement and mental workload in vigilance, learning, and memory tasks. Aviation, space, and environmental medicine, 78(5), B231-B244.
[13] Hsu, B. W., Wang, M. J. J., Chen, C. Y., & Chen, F. (2015). Effective indices for monitoring mental workload while performing multiple tasks. Perceptual and motor skills, 121(1), 94-117.
[14] Angel, J.M., R. Cristian, and L. Hernan, Using Psycho-Physiological Sensors to assess Mental Workload in Web Browsing. Sensors, 2018. 18(2): p. 458.
[15] Shaw, E.P., et al., Measurement of attentional reserve and mental effort for cognitive workload assessment under various task demands during dual-task walking. Biological Psychology, 2018. 134.
[16] Vergara, R.C., M. Cristóbal, and P.E. Maldonado, Cold-Blooded Attention: Finger Temperature Predicts Attentional Performance. Frontiers in Human Neuroscience, 2017. 11: p. 454.
[17] Dinges, D.F. and J.W. Powell, Microcomputer analyses of performance on a portable, simple visual RT task during sustained operations. Behavior Research Methods, Instruments, & Computers, 1985. 17(6): p. 652-655.
[18] None, Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4-5 hours per night. Sleep, 1997. 20(4): p. 267.
[19] Basner, M. and D.F. Dinges, Maximizing Sensitivity of the Psychomotor Vigilance Test (PVT) to Sleep Loss. Sleep, 2011. 34(5): p. 581-591.
[20] O'Hagan, A.D., et al., "Flying on empty" – effects of sleep deprivation on pilot performance. Biological Rhythm Research, 2019. 51(7): p. 1133-1154.
[21] Basner, M., et al., Repeated Administration Effects on Psychomotor Vigilance Test Performance. Sleep, 2018. 41(1).
[22] Ximena, F., et al., Sleep Duration and Results of the Psychomotor Vigilance Test in Construction Workers: A Preliminary Study, in Proceedings of the Creative Construction e-Conference 2020. 2020. p. 136-142.
[23] Joel, H. and B. Roger, Sensitivity of the stanford sleepiness scale to the effects of cumulative partial sleep deprivation and recovery oversleeping. Sleep, 1981(1): p. 83.
[24] Shahid, A., et al., Stanford Sleepiness Scale (SSS). stop that & one hundred other sleep scales, 2011.
[25] Fei, W., et al., Design of driving fatigue detection system based on hybrid measures using wavelet-packets transform. Proceedings - IEEE International Conference on Robotics and Automation, 2014: p. 4037-4042.
[26] Cazzoli, D., et al., Mean visual analogue scale (VAS) fatigue scores. 2014.
[27] Dario, C., et al., Correlation between visual analogue scale (VAS) fatigue scores and mean fixation durations. 2014.