Effect of Fatigue and Nervousness of Tower Controller on the Control Efficiency

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Abstract. Fatigue and nervousness are two of the most common bad states of air traffic controllers at work. To analyze the effects of fatigue and nervousness of tower controllers on the control efficiency, a tower control simulation experiment was designed to collect 22 participants' control performance data and the data of 19 participants were collected successfully. Four states, sober (SO), fatigue (FA), nervous (NE) and fatigue & nervous (FN), were designed. Seven indices of control efficiency were defined and analyzed, including three objective indices: task duration (TD), mean called frequency (MCF) by pilot per-flight and mean speech service time (MSST) for each flight and four subjective evaluation indices: instruction moment score (IMS), situation awareness score (SAS), transient mistake times (TMT) and result mistake times (RMT). The analysis results showed that all the indices were significantly different among the four states. Both fatigue and nervousness can impair control performance and reduce control efficiency. Under the influence of fatigue or nervousness, controllers' initiative and situation awareness will decrease and be more likely to make transient mistakes. At same time, controllers in fatigue state need more time and more communication speech per flight to manage the operation. Controllers in nervous state will make mistake more easily than sober and fatigue states. It can be inferred that fatigue mainly makes controllers' work speed slower and nervousness leads to more control mistakes. These findings are expected to improve the optimization of control efficiency and work management of air traffic.

Keywords: Tower controller · Control efficiency · Fatigue · Nervousness

1 Introduction

Air traffic controller, responsible to provide control services for flight, is one of the key units in air traffic service system. Controllers' working performance has crucial importance for air traffic operational efficiency and air traffic safety. A survey showed that about 52% air traffic management incidents were related with human error of controllers [1]. Maintaining good physical condition is the precondition of high working performance. However, there are some bad physical or mental states which may impair controllers' working performance and reduce control efficiency and safety. Fatigue and nervousness are two of the most common bad states for controllers at work. A report about the relation between human factor and incidents showed that 46.07% controllers

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admitted that they have the experience of fatigue duty and had high risk to result in incident [2]. The relation between air traffic safety and the bad states has been studied by some researchers. But it is not clear about the relationship between the efficiency and bad states of controllers. It is essential to explore the effect of the bad states on the efficiency to make better regulation policy for air traffic controllers and improve control efficiency.

There are very few studies focusing on the effect of fatigue and nervousness on control efficiency. Some researchers summarized that the bad states such as fatigue and nervousness will significantly impair the control performance. Controllers' ability will decrease under the influence of the states and some management policy need to be made [1–5]. Additionally, the characteristics of air traffic controller were explored. A study report indicated that fatigue can reduce controllers' ability to carry out a task significantly [6]. Some researchers also studied the detection method in real time based on controllers' facial expressions or work time [7–9]. We can get some fatigue characteristics of air traffic controller like eye movement from these studies. Much less of researches focused on the features of controllers' nervous state. However, these studies only stated the negative effect. The affecting aspect details of fatigue and nervousness on control efficiency are not clear.

Considering the lack of the effect characteristics of fatigue and nervousness on control efficiency, we tried to explore the characteristics in this study. The flight operational efficiency in airport, related with tower controllers' working performance, is the key point for flight rate and overall efficiency. Therefore, the purpose of this study was to analyze the effects of fatigue and nervousness of tower controllers on control efficiency and to analyze the effect differences of the two states. A tower control simulation experiment was designed to collect control data and some indices of control efficiency were defined and analyzed. The results are expected to provide useful references for work management and on-duty arrangement of controller team.

2 Method

2.1 Equipment

In order to collect control efficiency data under the influence of fatigue or nervousness without confounding factors on participants and considering the air traffic safety, a tower control simulator was used in this experiment. The simulator can provide virtual scenario of Qingdao Airport, as shown in Fig. 1. It consists of two radio communication microphones and seven network computers, which provide control system, approach radar, airport surveillance radar, virtual captain and three scenario display respectively. The airport scenario was projected onto three large screens in front, providing a 120° field of view. During the experiment, flights were designed in the control system firstly. Air traffic controller gave control commands to virtual captain through radio with assistance of the radar and airport view. Then, the captain control the flights to fly according to the commands. The speech of all controller in the experiment was recorded with 44100 Hz by a voice recorder, whose type is Sony PCM-D100.

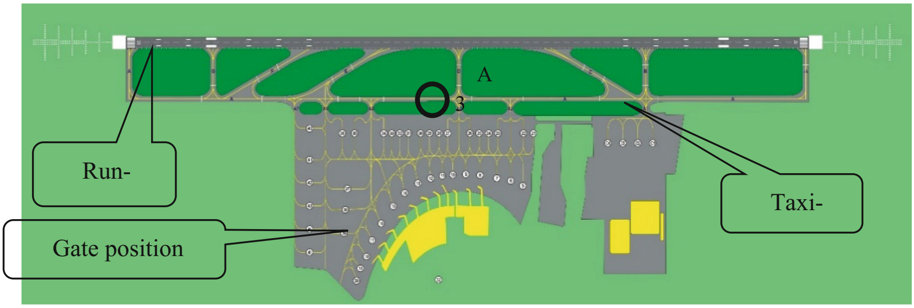

Fig. 1. Simulate airport in the experiment

2.2 Participants

Young air traffic controllers are the major part of frontline staff and compared with older controllers, they may lead to worse results under the influence of fatigue because of less work experience. At the same time, the novice may be nervous easily in control work. Thus, studying young controllers who work with fatigue or nervousness is crucial to improving air traffic safety. Furthermore, almost all the controllers in China are male. Therefore, 22 healthy, young male subjects were recruited to participate in the research. The average age was 24 (SD = 0.52, range = 23–26 years). All participants have possessed a valid controller's license and worked for 1 to 2 years (Avg. = 1.3). A regular circadian rhythm and no drug use were included in the recruiting criteria. We invested all subjects' sleep rhythm and drug use before recruitment. During each simulated control experiment, they were investigated drug use with a questionnaire. Only subjects with no drug use and no other physical change were allowed to do the experiment. Before recruitment, participants were required to have a test to be familiar with the control simulator and make sure they could perform task as well as the real circumstance. In addition, 4 veterans who are familiar with the flight running rules participated in the experiment to be virtual pilots. All participants agreed and signed an informed consent before participating in the study, and they were paid for their participation.

2.3 Experiment Design

To assess the effects of fatigue and nervousness on the control efficiency, participants were required to conduct experiments at four different states, sober (SO), fatigue (FA), nervous (NE) and fatigue & nervous (FN) states. The group in sober state was considered the control group and the groups in other states were treatment groups. In the experimental design, the key point is to induce fatigue and nervous state for participants. The fatigue state was designed mainly through experiment time according to the drivers' sleep rhythm and the nervous state through control task. The recruitment survey showed that they generally slept from 11 pm to 7 am of next day, had a noon break between 11:30 am to 1:00 pm and begin working again at 1:30 pm. Therefore, the SO and NE state experiments were executed at 9–11 am or 3–5 pm and they were required to sleep well at least three days before experiments to avoid the effect of fatigue. The FA and FN states experiments were designed to be carried out at 1 am to 3 am, when the participants would easily become fatigue. Also, the participants were required to get up before 8 am on the previous day and not to sleep before the experiment. At the same time, the control tasks in sober and fatigue states were designed as 6 departure flights and 6 arrival flights in about 30 min, which means that the participants can complete the task easily. In NE and FN states, the traffic flow were designed as 10 departure flights and 10 arrival flights in about 35 min and the taxiway of A3 was closed (shown in Fig. 1), which is a complex task to the participants to induce nervousness. The participants were asked to refrain from having any stimulating food or beverage, such as alcohol and drugs.

A questionnaire was used in the experiment to collect data on subjective fatigue and nervous degree. The fatigue degree was set to 7 levels: (1) active, alert, or wide awake; (2) functioning at high levels but not at peak or unable to concentrate; (3) somewhat foggy or let down; (4) foggy, losing interest in remaining awake or slowed down; (5) sleepy, woozy, or prefer to lie down; (6) sleep onset soon or having dream-like thoughts; and (7) asleep. The nervous degree was also designed to 7 levels: (1) very calm, accomplish the control task with ease; (2) calm and complete the task smoothly; (3) a little nervous sometimes; (4) nervous slightly and be not able to judge recollectedly; (5) nervous but be able to accomplish the task; (6) very nervous, only complete part task; (7) nervous very much and be not able to work.

Each participant was required to carry out the four states experiment in four separate days and the interval was at least 3 days. The order of the four states experiment for each participant was random. The procedure of each experiment was as follow:

- First, a participant was instructed regarding the operation of the simulator and the tasks in experiment. Then he was asked to get ready flight progress strip and be familiar with the simulator.
- Second, the questionnaire about subjective fatigue and physical state was completed. Only participant who met the designed criterion can carry out the experiment.
- Third, he was required to try his best to complete well the air traffic control experiment task. The air-ground communication speech, control mistakes and evaluation of control performance were recorded.
- Finally, at the end of experiment, the participant was asked to fill out the questionnaire survey to collect his subjective fatigue and nervous level in experiment.

In the experiment, the control tasks in SO and FA states were similar but different, as well as NE and FN states. In the process of experiment, every virtual captain was required to communicate with controllers with the same criteria to reduce interference on speech data.

2.4 Data Collection and Analysis

The simulated air traffic control data of 19 participants in the four states were collected successfully in the experiment. The participants were asked the fatigue level twice, before and after experiment. The two fatigue levels were used to evaluate the fatigue state during the experiment process. The mean subjective fatigue level of all participants in the experiment was shown in Fig. 2 and the nervous level in Fig. 3. It indicated that the fatigue level in the designed fatigue state was obviously higher than SO and NE states and it met our expectation, so was the nervous level.

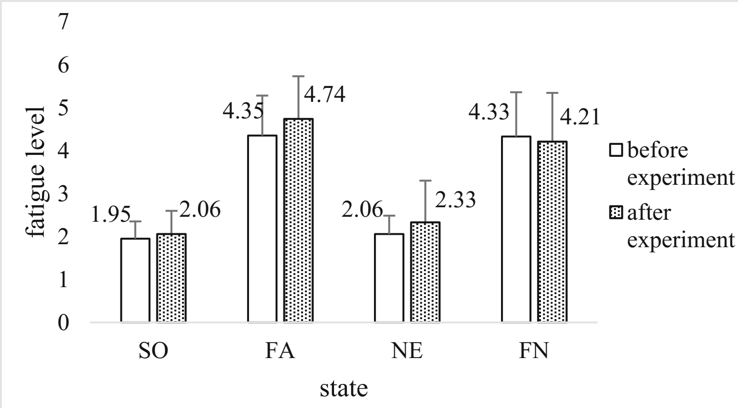

Fig. 2. Mean subjective fatigue level of all participants in the experiment

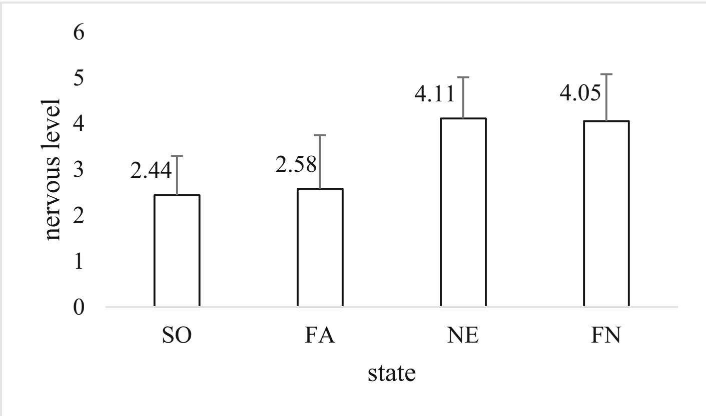

Fig. 3. Mean subjective nervous level of all participants in the experiment

In this study, the main purpose was to obtain the effect characteristics of fatigue and nervousness on control efficiency. Some objective and subjective indices were defined and calculated.

Firstly, three objective indices: task duration (TD), mean called frequency (MCF) by pilot per-flight and mean speech service time (MSST) for each flight were defined. TD was the whole duration of each control experiment, represented the overall working speed. Considering the similar control task in SO and FA states as well as NE and FN states, TD can be only used to analyze the effect of fatigue on control speed. MCF was defined as that divide the whole times of controller called by pilot in the air-ground communication speech by flight number. It can be used to explain the control initiative and efficiency. MSST was the average speech time duration that controller spent on each flight, representing the efficiency of control speech.

Secondly, four subjective evaluation indices: instruction moment score (IMS), situation awareness score (SAS), transient mistake times (TMT) and result mistake times (RMT) were calculated and extracted. During the experiment process, the control performance was evaluated and the indices were calculated based on the evaluation. IMS meant the timeliness of control instruction, with great importance for control efficiency. In calculation, once participant did not give instruction in appropriate time, certain score would be deducted according to detail situation. SAS was calculated with the same way. TMT meant the transient mistake such as instruction error, call-sign error and flight progress error of controller in once experiment. RMT was the occurrence number of unexpected situation like flight delay and go-around during each experiment. Both the mistake times were related closely with control efficiency.

To evaluate the effect of fatigue and nervousness on the above indices, ANOVA with repeated measures and contrast analysis were used to study the differences in different states. Each index was analyzed with ANOVA only considering one factor, state with four levels firstly. The interaction effect of fatigue and nervousness was also analyzed and discussed. In contrast analysis, we mainly focused on the contrast of FA VS SO state, NE VS SO state, FN VS FA state and FN VS NE state to discuss the effect of fatigue and nervousness on control efficiency.

3 Result

3.1 Effect of Fatigue and Nervousness on Objective Indices

The three objective indices were calculated based on the air-ground communication speech data, which was the main work pattern. The three indices from the four states were analyzed respectively. The results showed that they were all significantly different among the four states. The statistics analysis results of the three indices were shown in Table 1.

Table 1. Statistics analysis results for the three objective indices

Index	F	P	FA VS SO	NE VS SO	FN VS FA	FN VS NE
TD	145.35	<.001	.016	\	\	.001
MCF	8.15	.001	<.001	.048	.223	.010
MSST	140.91	<.001	.018	<.001	<.001	<.001

TD was obviously different in the four states and the means of it were shown in Fig. 4. No interaction effect of fatigue and nervousness was found for this index. The contrast analysis indicated that it was significantly longer in FA state (Avg. = 35.36, SD = 4.14) than SO state (Avg. = 32.56, SD = 2.84) and longer in FN state (Avg. = 47.62, SD = 4.51) than NE state (Avg. = 42.70, SD = 4.57). It meant that controllers needed more time to accomplish similar control task under the influence of fatigue, indicating that fatigue might impair the control speed.

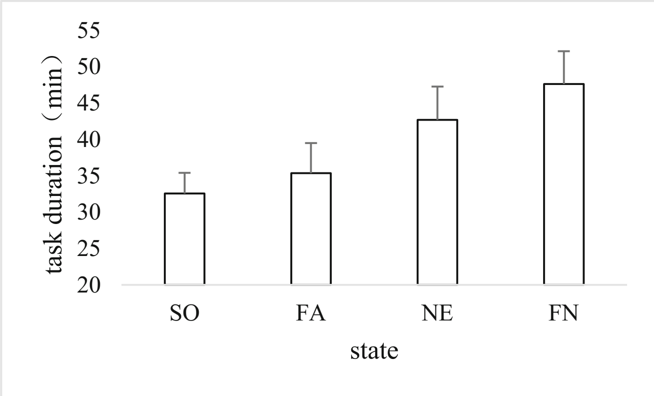

Fig. 4. Means of TD in the four states

The ANOVA analysis showed that MCF was significantly related with controllers' state and the means of it were shown in Fig. 5. No interaction effect of fatigue and nervousness was found for MCF. The contrast analysis showed that it was significantly more in FA (Avg. = 2.78, SD = 0.61) state and NE state (Avg. = 2.60, SD = 0.47) than SO state (Avg. = 2.37, SD = 0.44) and more in FN state (Avg. = 2.96, SD = 0.70) than NE state. MCF represented the initiative and control efficiency. The increase of it means the decrease of controllers' control ability and then he will be called by pilot more times to complete the task. The results showed that both fatigue and nervousness could impair control ability and efficiency. The significant difference between FN and NE but not

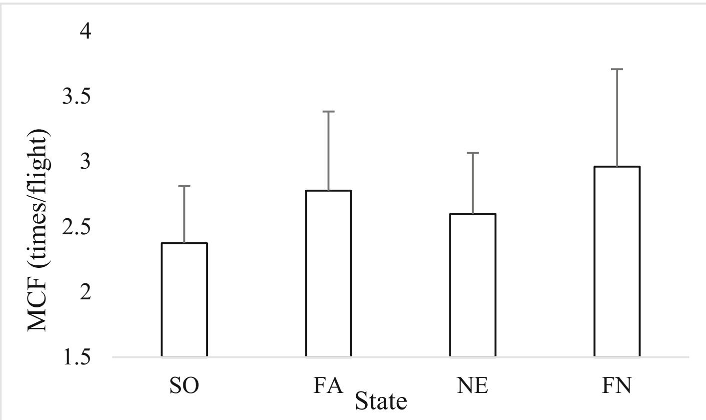

Fig. 5. Means of MCF in the four states

between FN and FA may indicate that fatigue has a more important role than nervousness in the effect.

MSST was significantly affected by state and the means of it were shown in Fig. 6. There was significantly interaction effect of fatigue and nervousness on MSST (p < .001). The contrast analysis showed that it was significantly different between any two states. MSST was longer in FA (Avg. = 38.51, SD = 3.60) state than SO state (Avg. = 37.93, SD = 3.37), shorter in NE (Avg. = 34.69, SD = 2.17) state than SO state and much longer in FN (Avg. = 45.60, SD = 3.77) state than FA and NE state. The results indicated that under the influence of fatigue, controllers need longer speech time to control each flight. However, the time became shorter when they were nervous. At same time, in FN state, controllers needed much longer speech time than any other states, which was due to the interaction effect of fatigue and nervousness.

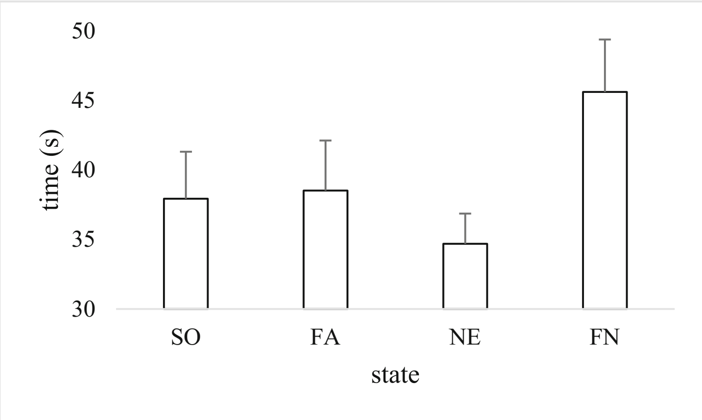

Fig. 6. Means of MSST in the four states

3.2 Effect of Fatigue and Nervousness on Subjective Indices

The four subjective indices were calculated based on the evaluation data for control process. The data was recorded by a veteran controller and evaluated according to a certain criterion. The four indices from the four states were also analyzed respectively. The results showed that they were all significantly different among the four states and no interaction effect of fatigue and nervousness was found for the indices. The statistics analysis results of the three indices were shown in Table 2.

Table 2. Statistics analysis results for the three objective indices

Index	F	P	FA VS SO	NE VS SO	FN VS FA	FN VS NE
IMS	10.14	<.001	<.001	.004	.016	.069
SAS	19.77	<.001	.018	<.001	.001	.662
TMT	20.04	<.001	.001	<.001	<.001	.106
RMT	12.96	.003	.120	.007	.023	.277

The ANOVA analysis results showed that IMS was significantly affected by controllers' state and the means of it were shown in Fig. 7. The contrast analysis revealed that it was significantly lower in FA (Avg. = −5.32, SD = 3.15) state and NE state (Avg. = −6.21, SD = 4.66) than SO state (Avg. = −2.47, SD = 2.57) and lower in FN state (Avg. = −9.42, SD = 5.91) than FA state. IMS represents the ability of giving control commands at the right moment, which is important for control efficiency. The analysis results showed that both fatigue and nervousness would affect this ability. The obviously differences between FN and FA state but not between FN and NE may reveal that nervousness impairs the ability of instruction moment more seriously.

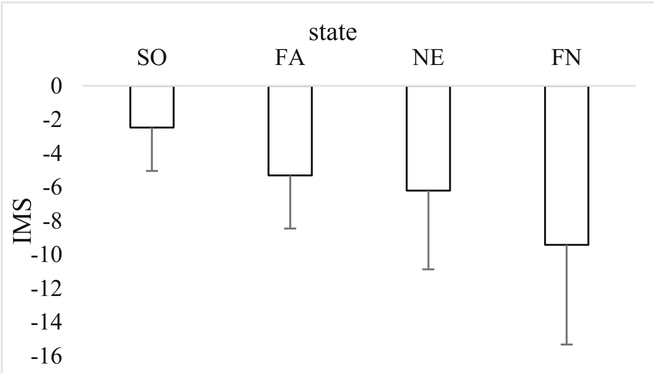

Fig. 7. Means of IMS in the four states

The analysis results of SAS indicated that it was also significantly related with controllers' state, as shown in Fig. 8. The contrast analysis revealed that it was significantly lower in FA (Avg. = −5.16, SD = 4.32) state and NE state (Avg. = −10.89, SD = 5.38) than SO state (Avg. = −2.26, SD = 2.25) and lower in FN state (Avg. = −11.63, SD = 4.27) than FA state. SAS represents the comprehensive air traffic control ability in the working process. Situation awareness is crucial for controllers to have correct

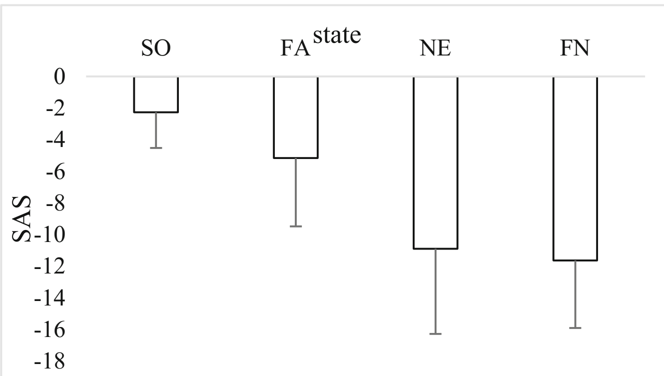

Fig. 8. Means of SAS in the four states

judgment and give appropriate control commands. The results showed that the ability would be impaired by fatigue and nervousness. The comparison may also reveal that nervousness affects the ability of situation awareness more seriously than fatigue.

TMT was significantly affected by state and the means of it were shown in Fig. 9. The contrast analysis showed that it was significantly more in FA (Avg. = 10.84, SD = 4.54) state and NE state (Avg. = 16.58, SD = 7.22) than SO state (Avg. = 7.26, SD = 3.03) and more in FN state (Avg. = 20.16, SD = 10.07) than FA state. TMT is the statistics for controllers' control errors, representing the characteristics of control process. The analysis results revealed that under the influence of fatigue or nervousness, controllers would make more control mistakes. The obviously differences between FN and FA state but not between FN and NE may still indicate that nervousness will lead to more errors than fatigue.

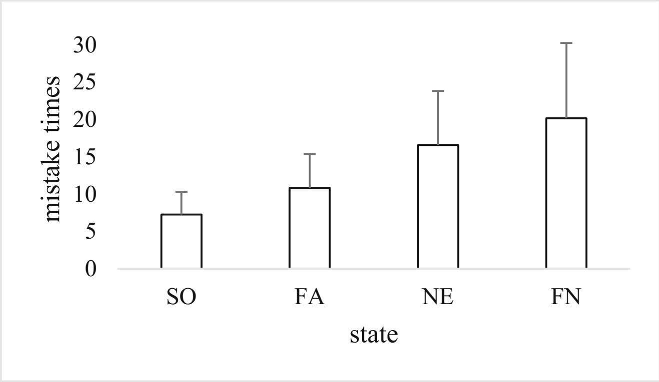

Fig. 9. Means of TMT in the four states

The analysis results showed that RMT was significantly related with state, as shown in Fig. 10. It was significantly more in NE state (Avg. = 2.26, SD = 1.69) than SO state

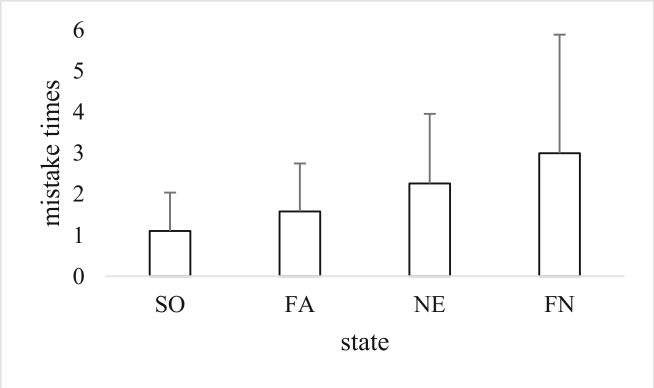

Fig. 10. Means of RMT in the four states

(Avg. = 1.11, SD = 0.94) and more in FN state (Avg. = 3.00, SD = 2.8) than FA state (Avg. = 1.58, SD = 1.17). RMT is the evaluation of control performance, representing the characteristics of control result. The analysis results indicated that nervousness would generate more bad traffic situations. The comparison between FN and FA state also proved the significant effect of nervousness on control result mistake.

4 Discussion

The analysis results indicate that all the indices are significantly different in different states. Under the influence of fatigue, controllers' control speed will be slow, initiative decrease, control ability on instruction moment and situation awareness decrease and control mistake increase. When working in nervous state, controllers' control speed will be slow and initiative decrease slightly, but make much more transient and result mistake. Fatigue and nervousness have significant interaction effect on the speech service time for each flight.

For the effect of fatigue, it may be easily understood that the control speed become slower in fatigue state. It has been proved that people's somatic function will become slower [10]. The controllers' ability of perception, reaction and action will weaken when fatigue. All of these changes characteristics will lead to slower of controllers' action, including decision-making and speech speed. Considering these change characteristics, we can deduce that controllers' mentality will be lazy, which make their initiative decrease. Because of these reasons, controllers will need more time and more speech time to complete task and be called more times by each pilot. At the same time, the decrease of control ability on instruction moment and situation awareness is also due to the impairment of fatigue on somatic function. Then, the decrease of ability results in the increase of control mistakes. It can be summarized that fatigue impairs comprehensive control ability and mainly decrease processing speed and mentality initiative. Control efficiency will be significantly decline under the influence of fatigue.

For the effect of nervousness, the mainly reason may be the complicated and heavy control task for controllers. The higher MCF may be due to that controllers cannot deal with every flight immediately because of vast control task from much more flight. In nervous experiment, due to that controllers need to accomplish plenty of control task in certain time, the speech speed might become faster and then lead to lower mean speech service time. Similarly, the control task was very complex in the situation of high traffic flow, making nervous state for controllers. They could not give appropriate commands to each flight timely and hold the running situation correctly under the influence of nervousness. Then more control mistake appeared during the control process. In a word, heavy control task is easy to cause nervous state and nervousness affects control efficiency mainly through control performance. Much more mistakes may appear under the influence of nervousness.

The interaction effect of the two bad states only appeared in the index of MSST. It could be deduce that fatigue impaired control ability firstly and in the FN state experiment, controllers ability could not met the need of the complicated task. Then they had to spend much more speech time to complete the task. At the same time, it can found that under influence of both fatigue and nervousness, every index showed the worst result. We can conclude that the combination of more bad states will impair control performance and efficiency much more seriously.

The results of this study showed some characteristics effects of fatigue and nervousness on control efficiency. The results have potential application in practical use. They are helpful to have a better understanding on the effect characteristics of fatigue and nervousness on control ability and make countermeasure. The results also provided a reference for further study on the effect characteristics of controllers' state. In further study, more indices of control performance need to be analyzed and some countermeasures will be studied to prevent the impairment on control efficiency.

5 Conclusion

This paper explores the effect of controllers' fatigue and nervousness on control efficiency, 7 indices were defined and analyzed. They can explain different aspects of control efficiency. Based on the analysis results, the following conclusions can be made:

- Fatigue can make controllers' control speed be slower and control initiative decrease. Their control ability on instruction moment and situation awareness will be impaired by fatigue and more transient mistake will appear in control process.
- Complicated control tasks are easy to lead to controllers' nervous state. Under the influence of nervousness, controllers' control speed and initiative will decrease. Nervousness will result in much more transient and result mistake.
- Controllers need much longer speech time per flight to complete task because of the interaction effect of fatigue and nervousness. Under the influence of the two states simultaneously, the control performance will become much worse.
- Comparing the effect characteristics of the two state, fatigue mainly makes controllers' work speed and initiative decrease due to decline of somatic function. Nervousness mainly leads to more control mistakes because of the intricate task.

In summary, both fatigue and nervousness will impair air traffic controllers' work ability and control efficiency. These effect characteristics are expected to provide reference for the work management of air traffic controller.

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