



Effect of Mental Fatigue on Visual Selective Attention

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Abstract. To explore the effect of human mental fatigue on their visual selective attention, and carry out ergonomic design in monitoring operation system. Thirty-two men participated the experiment, 140 min digital 2-back task was used to simulate the monitoring work to induce mental fatigue, then simulation of automatic alarm based on 2×3 factors cue-target paradigm was used to measure the selective attention ability. The influence of mental fatigue on visual selective attention was explored by analyzing behavioral and event-related potentials data. The results showed that 140 min 2-back cognitive task induces mental fatigue successfully. Under the condition of mental fatigue, the invalid cue and the target stimulus in central cue-target paradigm had the strongest fatigue effect, while the effective cue and the interfere stimulus had the weakest. The subjects' performance of the selective attention task decreased and P300 latency was significantly prolonged and amplitude decreased significantly, mental fatigue has a negative effect on visual selective attention.

Keywords: Mental fatigue · Visual selective attention · 2-back · Performance · Electroencephalogram (EEG)

1 Introduction

With the rapid advancement of electronic informatization, the amount of information has increased dramatically, and the types of information that need to be processed by humans are richer and more numerous. The role of people in the system is no longer a simple operator, but tends to be more of a monitor and a decision maker. On the one hand, the complexity and variety of job tasks led to a significant increase in the operator's cognitive and mental workload; on the other hand, the operators were under tremendous mental stress while completing the task for a long time [1]. Therefore, operators were more likely to fall into fatigue due to long-term accumulation of mental workload and increased psychological stress. This mental fatigue was a limited state of the brain due to the completion of long repeated tasks [2].

The information processing capability of the brain is limited. Selective attention was to focus limited cognitive resources on important aspects of important things or things, which helps to improve information processing efficiency [3]. During the information operation, the operator needs to monitor the system status for a long time and make a correct response after sensing the system signal. This requires the operators had strong visual selective attention, maximize the operational ability, and improve information processing efficiency [4]. In the state of mental fatigue, the operators' attention ability and performance decreased, and the error rate increased. This situation might even lead to an accident [5]. Therefore, it is of great theoretical and practical significance to study the effects of mental fatigue on visual selective attention and to explore the quantitative changes of visual selective attention after mental fatigue.

It is difficult for people to concentrate when they are mentally fatigued. Existing research showed that mental fatigue induced by continuous cognitive operation has varying degrees of influence on selective attention [6–8]. For example: Zhang simulated 6 h driving task induced mental fatigue of the subject, and found that the individual noticed that the processing function was impaired, but the information processing speed was not damaged [6]; Mun et al. studied the effects of mental fatigue caused by moving 3D images on selective attention ability, and found that mental fatigue can impair spatial selective attention [7]; Faber et al. used a 120-min lateral inhibition task to induce mental fatigue, which also demonstrated that mental fatigue affects selective attention, and that the degree of fatigue increases, and the inhibitory ability of distraction stimulation decreases [8].

There are many studies on the effects of mental fatigue on selective attention, but the impact of its impact mechanism, especially on the visual selective attention ability of participating in surveillance operations, is unclear. At present, selective attention at home and abroad is based on basic research, and selective attention has not been combined with specific engineering applications [3, 4]. Therefore, the author will simulate the monitoring and alarm platform in the real scene, and use the memory refresh test (2-back task) to simulate the monitoring process to induce the mental fatigue process, in order to provide a theoretical basis for the operator's risk assessment under the condition of mental fatigue.

2 Method

2.1 Participants

A total of 32 subjects were recruited and randomly assigned to the normal and fatigue groups, each group of 16. All the subjects were male, aged 20 to 30 years old, bachelor degree or above, right hand, no red and green blindness, no difference in sensitivity to red and green color; normal cognitive ability, good sleep habits, no smoking, alcoholism Other bad habits, no irritating substances such as alcohol and caffeine were ingested within 4 h before the start of the test.

2.2 Experimental Tasks

The trial used the 140 min 2-back paradigm task, requiring participants to compare whether the current content is consistent with the target stimulus. And by constantly refreshing short-term memory, the nerve cells became fatigued, and the brain resources were quickly depleted, thus truly making the brain itself fatigued [9].

The visual selective attention test used a central clue (CC) to prompt the task, in which the cue clue appears at the center of the screen or does not appear, using a 2×3 design. And the independent variable A indicated the clue validity (effective clue (EC), invalid clue (IC), no clue (NC)). Independent variable B indicated the stimulus color (red, green). The six situations of clue validity and stimulus color interaction corresponded to the automatic alarm platform hit (H), false alarm-0 (FA-0), false alarm-1 (FA-1), false alarm-2 (FA-2), missing report (M), no warning (N) 6 cases, and the parameter settings for the clue prompt task were shown in Table 1. The single subprocess (trial) of the clue prompt task consisted of 4 pictures, and a black block appeared inside the center ring of the leftmost picture. After a period of time, the position of the outer ring corresponding to the quadrant of the black block might appear as red or green targets. Red as the target represented a small probability event, and green as a disturbance represented a high probability event. The task interface was shown in Fig. 1. After the red target appeared, the subjects were asked to quickly press the “F” key with left index finger, and after the green interference occurred, to quickly press the “J” button with right index finger. Each trial contained 240 trials, of which the ratio of missing report, hitting and false alarm is 1:3:13. Subjects were asked to keep

Table 1. Parameter setting for central cue-target paradigm

Position	Type	Color	Monitoring work	Press	Trials number
CC	EC	Red	H	F	36
		Green	FA-0	J	108
	IC	Red	FA-1	F	12
		Green	FA-2	J	36
NC	NC	Red	M	F	12
		Green	N	J	36

their eyes on the center of the word “Ten”. Red as the target and green as the interference, the purpose was to pass the message “Red represents danger signal, and green represents safety signal” to the subject, so that the test interface and the operation of the subject matched the automatic alarm monitoring platform.

2.3 Procedure

The experiment was conducted as follow procedures:

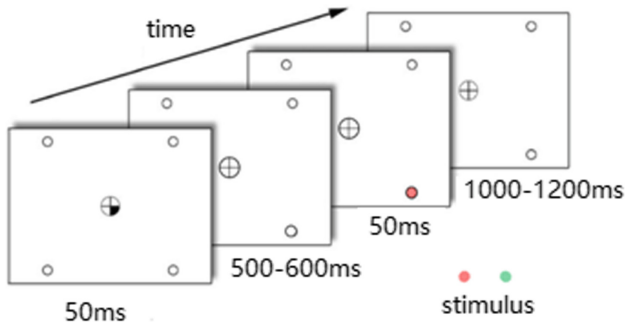


Fig. 1. The sketch map of task interface (Color figure online)

1. The subjects were asked to practice the experimental tasks to familiarize the trial operation and minimize the learning effect. The data in the practice session was not used for statistical analysis.
2. The two groups of subjects completed the 7 min clue prompt task (selective attention ability pretest).
3. Filled in the mental state subjective questionnaire (subjective questionnaire pretest).
4. The normal group and the fatigue group completed the 10-min 2-back task (2-back pretest).
5. The normal group rested for 120 min, while the fatigue group needed to continue to complete the 120 min 2-back task.
6. After the two groups of subjects completed the 10-min 2-back task (2-back post-test), the mental fatigue induction phase ended.
7. Two groups of subjects completed the subjective questionnaire of mental state (post-subject questionnaire) and completed the clue prompt task for about 48 min (selective attention ability post-test).

The entire test process took about 190 min. The electroencephalogram (EEG) signals were collected during the test. The scalp impedance was controlled to less than 5 k Ω and sampling rate was 1000 Hz.

3 Results

3.1 2-Back Mental Fatigue Induced Results

(1) Behavioral data

On the subjective evaluation data, there was no statistically significant difference in subjective fatigue before and after brain fatigue induction in the normal group. For the fatigue group, the subjective fatigue after brain fatigue induction was significantly higher than that before induction, and there were significant differences in thinking clarity, attention concentration, sleepiness, fatigue state and emotional state ($p < 0.05$). Therefore, 140 min of 2-back task significantly increased subjective fatigue.

Comparing the performance data of the 2-group pre-test and post-test tasks in the normal group operation, it was found that the difference in response time, stability, error rate and miss rate of the pre-test and post-test tasks was not statistically significant. Comparing the performance data of the 2-back pre-test and post-test tasks of the fatigue group, it was found that the response time of the post-test task decreased, but it was not statistically significant ($t = 1.219$, $p = 0.233$), and the stability did not change significantly ($t = -0.029$, $p = 0.977$), the error rate increased significantly ($t = -2.276$, $p = 0.032$), and the missing rate increased slightly, but it was not statistically significant ($t = -1.290$, $p = 0.208$). The above analysis validated the effectiveness of the 140 min 2-back task-induced mental fatigue from the perspective of behavioral data.

(2) EEG data

P300 components were extracted from EEG data to analyze the correct response of the subjects to the stimulus corresponding to the operation's EEG fluctuations. The magnitude of P300 reflected the amount of mental resources invested in performing cognitive tasks. The length of the incubation period reflected the speed of cognitive processing [10].

The P300 amplitude and latency of the 2-back pre-test and post-test tasks were analyzed statistically in the normal group and the fatigue group. It was found that there was no significant change in the P300 amplitude and latency of the normal group before and after the mental fatigue induced task. Therefore, from the perspective of EEG data, it was proved that the 20 min 2-back task did not cause mental fatigue. Before and after the brain fatigue induced task, the P300 amplitude of the fatigue group did not change significantly, and the latency was significantly prolonged ($p < 0.05$).

The 140-min 2-back operation in the fatigue group was divided into 14 segments on average (i.e., pre segment, 1–12 segment, post segment, each segment 10 min). The changes of P300 amplitude and latency of each segment with time were shown in Figs. 2 and 3. Fz, Cz and Pz electrodes were selected to represent three brain regions: the middle frontal region, the vertex region and the apex region respectively. In the first 50 min of the 2-back task, P300 amplitude and latency showed an upward trend, indicating that the brain resources of the participants were increasing, but the cognitive process of the stimulus signal became slower, and the time required for information perception and processing was prolonged. It showed that the fatigue of the subjects is deepening. At the 60th minute of the 2-back task, the amplitude of P300 suddenly dropped, indicated that the subject did not mobilize too much brain resources, and the effort on information processing decreased. At the same time, the latency of P300 decreased slightly, indicating that the processing speed of stimulus information was slightly accelerated, indicating that the operation of the subject became sloppy at this time. 80 min after the 2-back task (paragraph 6-post), the fluctuation range of P300 amplitude was large, which was believed to be caused by the subject's subjective self-motivation and adjustment. The latent period of P300 presented an upward trend, indicating that the subject was still in a state of mental fatigue during this period. Based on the above analysis, it was further proved from the perspective of EEG that the 140 min 2-back task successfully induced mental fatigue.

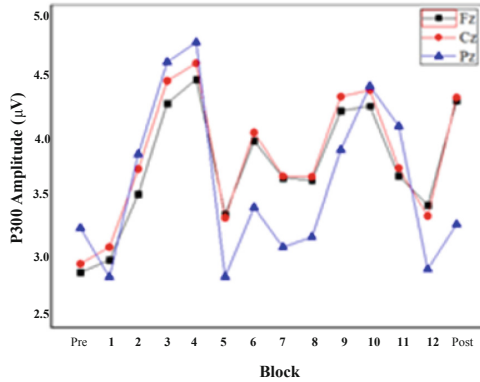


Fig. 2. Each segment’s P300 amplitude of fatigue group (Color figure online)

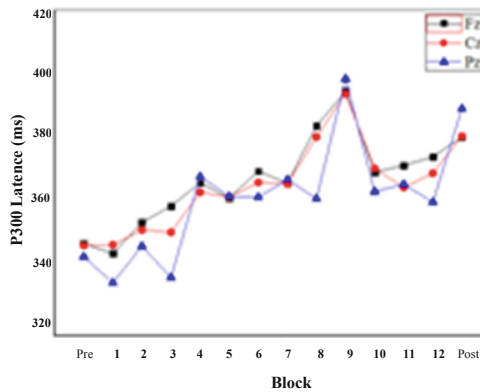


Fig. 3. Each segment’s P300 latency of fatigue group (Color figure online)

3.2 Visual Selective Attention Ability Test Results

(1) Behavioral data

Table 2 was the descriptive statistics of the performance data of operation clues and post-test tasks in the normal group (NG) and the fatigue group (FG). Compared with the normal group, the error rate (ER) and the missing rate (MR) of the fatigue group increased. The reaction time (RT) increased, and the operation performance deteriorated.

Statistical analysis of the normal group and fatigue group of the performance of the operation clues hinted after the test task data. In the reaction time, the main effect of the grouping factor was significant ($F = 4.446, p = 0.044$), and the interaction effect of color * group was significant ($F = 7.617, p = 0.010$); Simple effect analysis was carried out, and it was found that the effect of grouping factors was affected by color factors. When only green stimuli appeared, there were statistical differences in reaction

Table 2. Performance data on the normal group and the fatigue group after post test task ($x \pm s$)

		EC		IC		NC	
		Red	Green	Red	Green	Red	Green
NG	RT (ms)	449.200	337.667	469.333	428.429	493.400	410.733
		(49.124)	(40.739)	(57.568)	(66.232)	(53.341)	(49.117)
	ER	0.094	0.005	0.047	0.006	0.063	0.005
		(0.064)	(0.004)	(0.037)	(0.005)	(0.046)	(0.005)
	MR	0.014	0.012	0.014	0.020	0.011	0.034
		(0.015)	(0.009)	(0.015)	(0.023)	(0.009)	(0.034)
FG	RT (ms)	474.929	389.286	494.571	381.000	524.000	486.929
		(67.722)	(63.585)	(70.099)	(43.619)	(64.649)	(73.921)
	ER	0.100	0.013	0.083	0.019	0.075	0.011
		(0.100)	(0.012)	(0.076)	(0.024)	(0.079)	(0.015)
	MR	0.049	0.045	0.045	0.052	0.060	0.092
		(0.059)	(0.053)	(0.057)	(0.063)	(0.072)	(0.095)

time between normal group and fatigue group ($F = 0.138, p = 0.008$). At this time, the effect of mental fatigue on wireless clue was greater than the effective clue, and the degree of influence on effective clues was similar to that of invalid clues. In terms of error rate, the main effect of grouping factors was not significant ($F = 1.000, p = 0.326$), and there was no significant interaction between grouping factors and other factors. In the miss rate, the main effect of the grouping factor was significant ($F = 6.107, p = 0.020$), and there was no significant interaction between the grouping factor and other factors.

Further analysis of the main effects and interaction effects of intra-group factors (color, validity), was made that the main effect of color factors was significant in response time ($F = 141.227, p = 0.000, \text{red} > \text{green}$). Effectiveness factors of the main effect was significant ($F = 110.777, p = 0.000$). In terms of error rate, the main effect of the color factor was significant ($F = 40.620, p = 0.000, \text{red} > \text{green}$). When and only when the red stimulus appears, there was a significant difference in the error rate of the subjects under different clues. The error rate of the subject under the valid clue was significantly larger than the invalid clue ($F = 0.032, p = 0.002$) and Wireless clue ($F = 0.028, p = 0.021$). In the miss rate, if and only if the wireless clue prompts, the miss rate for green stimulus was significantly greater than the red stimulus ($F = -0.028, p = 0.001$). If and only if the green stimulus appears, the miss rate of the participant under the wireless clue prompt was significantly larger than the effective clue ($F = -0.035, p = 0.001$) and the invalid clue ($F = -0.027, p = 0.004$).

Therefore, under the clue prompt, the subject selectively paid attention to the large probability event, and the operation of the small probability event was easy to make mistakes. Under the wireless clue prompt, the subject selectively paid attention to the small probability event, and the operation of the large probability event was easy to be missed. Mental fatigue caused the subject's performance to deteriorate. The effect of mental fatigue on wireless clue was greater than that of clues, and the degree of

influence on effective cues was similar to that of invalid cues. The effect of mental fatigue on red stimuli was greater than that of green stimuli.

(2) EEG data

Statistical analysis of the normal group and the fatigue group operating clues prompted the post-test task P300 amplitude, latency, descriptive statistical results were shown in Table 3. Compared with the normal group, the latency of P300 in the fatigue group was significantly prolonged ($p < 0.05$). The amplitude of the P300 was significantly reduced ($p < 0.05$).

Table 3. P300 amplitude and latency of the cue-target paradigm in the normal group and the fatigue group ($\bar{x} \pm s$)

Factors		EC		IC		NC	
		Red	Green	Red	Green	Red	Green
NG	Amplitude/ μV	3.93 (1.48)	1.89 (1.17)	3.99 (1.74)	2.14 (1.49)	3.46 (1.62)	1.46 (0.80)
	Latence/ms	377.43 (13.31)	386.63 (15.47)	389.98 (9.85)	403.21 (11.85)	391.00 (11.78)	403.41 (12.36)
FG	Amplitude/ μV	3.33 (1.49)	1.30 (0.72)	3.11 (1.96)	1.23 (0.65)	2.23 (1.49)	1.08 (0.63)
	Latence/ms	390.59 (11.71)	388.28 (17.30)	397.06 (6.09)	413.84 (10.13)	420.82 (9.88)	406.82 (10.33)

For the P300 amplitude, the main effect of the grouping was significant ($F = 17.314$, $p = 0.000$), and the main effect of the color was significant ($F = 194.088$, $p = 0.000$). The main effect of validity was significant ($F = 12.167$, $p = 0.000$), and the interaction effects were not significant. For the P300 latency, the main effect of the grouping was significant ($F = 56.894$, $p = 0.000$), and the color * validity * grouping interaction was significant ($F = 3.348$, $p = 0.000$). Further analysis of the interaction effect found that the fatigue effect of red stimulation and green stimulation was significant ($F = 96.570$, 5.840 , $p = 0.000$, 0.022); effective clues, invalid clues, fatigue effects of wireless cables was significantly ($F = 7.190$, 17.270 , 96.530 , $p = 0.012$, 0.000 , 0.000).

The results of P300 analysis showed that the fatigue effect of invalid clues and red stimuli is the strongest, and the fatigue effect of effective clues and green stimuli was the weakest, and indicated that there are more brain resources required for invalid clues and small probability events, and less brain resources required for effective clues and high probability events.

4 Discussion

The 140-min digital 2-back task successfully induced mental fatigue. By analyzing the behavior and the P300 data of the fatigue group, it was found that the subjective fatigue of the fatigue group was significantly higher than that of the normal group, and the reaction time and stability showed strong fluctuations. Error rate and omission rate showed an upward trend. On the EEG data, the P300 amplitude of the fatigue group showed strong volatility, and the P300 latency period showed an upward trend. It was found that the subject reach the mental fatigue state after 60 min. With the extension of the task time, the degree of mental fatigue was constantly deepening. Consistent with previous studies, Horat et al. also found that the P300 latency is prolonged as mental fatigue deepened [11].

Mental fatigue affects visual selective attention ability, and the results of performance data showed that mental fatigue leads to poor performance of subjects, which has a greater impact on non-cue than on cue, and a similar impact on effective cue and invalid cue. The results of P300 showed that the fatigue effect of invalid clues is the strongest, while that of effective clues was the weakest. There were some differences between this conclusion and the conclusion of performance analysis. The reason was that human behavior is not only affected by the cerebral cortex, but also involves a series of executive control links. Performance data cannot accurately reflected the real state of mind, and Event Related Potentials (Event - Related Potentials, ERPs) as a cognitive characteristics study of the characteristics of the most direct, strongest time resolution could be better objectively reflect the state of cognitive and mental load, is an effective indicator of cognitive and mental fatigue analysis. The fatigue effect of red stimulus was the strongest, while the fatigue effect of green stimulus was the weakest, indicating that more mental resources are needed for invalid clues and low-probability events, while less mental resources are needed for effective clues and high-probability events. This conclusion was consistent with the conclusion of performance analysis. Green stimulation was a high probability event. In comparison, the process of the high probability event was more automated during the test. Therefore, the brain resources needed to respond correctly to green stimuli are few. The red stimulus was a small probability event. To respond correctly to the red stimulus, more brain resources needed to be called to identify and judge the stimulus. In consequence, the response to green stimuli was faster and more accurate, and the response to red stimuli was slower and more error-prone.

5 Conclusion

Brain power fatigue was induced by continuous operation of the digital 2-back task for 140 min, and the selective attention ability was measured by the central cue paradigm to explore the effect of brain fatigue on visual selective attention. Conclusions were drawn as follows:

By analyzing behavioral data and EEG data, it was proved that the 140 min 2-back task successfully induces mental fatigue. Therefore, when the task is completed for a long time, the mental fatigue will be induced, which will affect the performance of the

operation. The main solution at this stage was the shift and rest of the personnel. In the future, the adaptive assignment task system can be applied to dynamically assign tasks according to the personnel load status, thereby improving man-machine compatibility.

The negative impact of mental fatigue on the ability of visual selective attention leads to poor performance of the test, prolonged latency and reduced amplitude of P300; the fatigue effect of invalid clues and target stimulation is the strongest, and effective clues and interference stimulation is the weakest. Therefore, the number of invalid leads should be appropriately reduced when designing the monitoring operating system.

This article is only a preliminary study of mental fatigue. In the future, other components of ERPs need to be extracted, combined with ECG, eye movement and other physiological indicators, to further explore the indicators of mental fatigue and selective attention.

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