The Effect of Thirty-Six Hour Total Sleep Deprivation on Spatial Cognition and Alertness

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Abstract. **Objective:** To explore the effect of total sleep deprivation (TSD) for 36 h on spatial cognitive ability and alertness in normal youth. **Methods:** Six healthy young men aged 22–26 were enrolled in this study. Mental rotation tests and KSS measurements were performed once every hour under 36 h TSD. **Results**: Accuracy of the mental rotation ability test first increases and then decreases during the day. KSS scores increase with TSD time in a 12-h cycle. **Conclusion**: Under the condition of total sleep deprivation for 36 h, the spatial cognitive ability of normal youth declines to a certain extent, and their own learning and proficiency greatly influences mental rotation test scores. Alertness of normal youth continued to decline over 36 h of TSD, and fatigue gradually increased.

Keywords: TSD · Spatial cognitive ability · Alertness · Biological rhythm
Aviation safety

1 Introduction

In recent years, the Chinese civil aviation industry has been greatly developed, and the total transport turnover is second only to the United States [1]. Civil Aviation Administration of China statistics shows: In 2016, the national airport of civil aviation transport completed a passenger throughput of 1.016 billion passenger trips, an increase of 11.1% over the previous year [2]. The number of civil aircraft airports completed 9,238,000 movements, an increase of 7.9% over the previous year. The performance of civil aviation has increased year by year, which has led to the continuous operation of civil aviation workers under high load conditions or continuous work around the clock, which seriously affects the safe operation of civil aviation. Considering the example of civil aviation air traffic controllers, first-line air traffic controllers adopt a 24-h shift system. Long-term shifts, heavy work intensity, time pressure, and work environment can easily result in sleep deprivation and fatigue, which jeopardizes control, work safety, and efficiency [3].

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To perform efficiently, the controller must command the height, speed, and direction of the plane in three-dimensional space, and the pilot must operate the aircraft in three-dimensional space. It is necessary to have good spatial cognitive ability [4]. Visual image is an important aspect of spatial cognitive ability and may be manifested in many different ways, the most typical being appearance-based mental rotation [5]. Mental rotation is not only a typical cognitive activity of visual space but also one of the main indicators to assess the cognitive level of directional orientation in flight space [6]. During total sleep deprivation (TSD) there is no sleep for at least 24 h. This leads to a series of changes in emotion, learning and memory, immune function, etc. With increase in fatigue, a series of physiological, psychological and even behavioral changes is manifested [7]. Therefore, it is particularly important to study the changes of mental rotation and alertness of normal youth under TSD. The present study aimed to explore the effects of 36 h TSD on mental rotation and alertness of normal young individuals.

2 Method

2.1 Participants

Six healthy male youth, aged 22–26 years; height 178 ± 3.7 cm, weight 70 ± 5 kg; physical health; no sleep disorders, mental illnesses, or family history of these diseases; regular sleep routine (sleep at about 22:30 and wake up at 7:30); no recent medications, were included in the study, All participants agreed and signed informed consent before participating in this experiment. And this research was approved by Civil Aviation University of China.

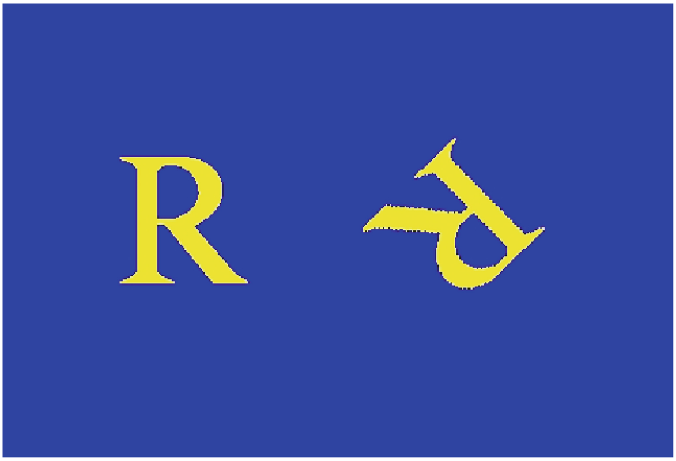
2.2 Procedures

For one week prior to the experiment, all experimental participants were directed to rest on schedule. They were banned from consuming alcohol, strong tea or coffee, performing strenuous exercise, and were prohibited from taking drugs that inhibit or excite the central nervous system. In the two days prior to the experiment, experimental procedures were explained and simulated to allow the participants to reach a degree of familiarity with the experimental procedures and instruments, and to achieve better experimental results. After two days of normal sleep, experimental procedures began at 8:00 on the day of the experiment, and ended the following day at 20:00. Mental rotation tests and Karolinska sleepiness scale (KSS) measurements were administered every hour, and total sleep deprivation (TSD) for 36 h was achieved. Six staff members took turns to supervise the participants and prevented them from taking a nap (TSD quality is considered substandard if napping occurs for more than 3 min).

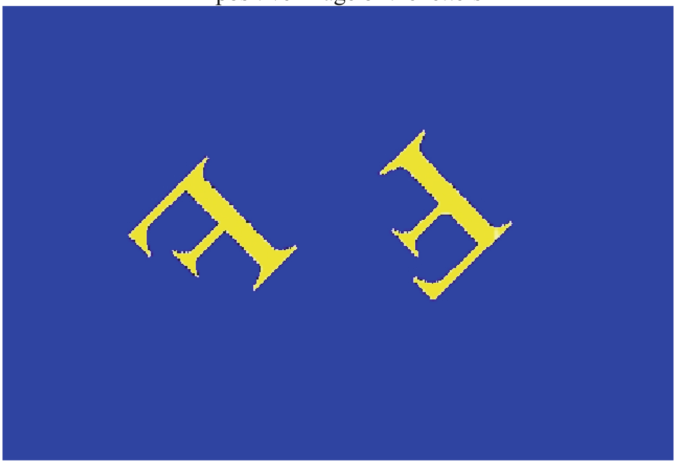
2.3 Apparatus

Test of mental rotation ability (TMRA) was performed using a DXC-6 wireless multi-group psychological evaluation instrument, made by the Department of Aerospace

Medicine of the Fourth Military Medical University of China. The test was expressed by the English capital letters G, F, and R, The two letters were about 1.0° × 7.9°, and the shape area was not more than 1.58 cm × 6.66 cm. The screen presents a pair of the same English letters, two "G", two "F", or two "R", which had either a positive image or mirror image relationship. The participant was asked whether the rotation of one letter would allow it to perfectly superimpose the other (as was the case for the positive image). If this was the case, they were asked to press the "yes" key; otherwise, if the letters were mirror images, they were asked to press the "no" key.



A positive image of the letters



A mirror image of the letters

TMRA is stimulated by visual channels to respond to motion, to detect spatial cognitive ability, psychological appearance, and judgment and reasoning ability. During the experiment, six participants were tested at the same time and measurements were performed every hour. The participants were asked to judge and answer questions in the shortest time possible. The computer automatically recorded the time elapsed from the presentation of the stimulus to the participant's response and the correct number of responses. The difficulty levels of the questions were approximately the same, and the correct number of answers was selected as the experimental indicator to characterize the participants' spatial cognitive ability.

There are five options for Karolinska sleepiness scale (KSS): 1-very alert; 2-alert; 3-general; 4-sleepy; 5-very sleepy. Participants rated their sleepiness on the scale of 1–5.

2.4 Statistical Analysis

Six participants successfully completed the experiment, and none of the participants were permitted to exit during the experiment. TMRA data includes the correct number of answers, and KSS data includes the participants' self-assessment drowsiness values. Data analysis was carried out using SPSS 11.0 statistical package, MATLAB R2014a for data processing, measurement data was represented by ($x \pm s$), $p < 0.05$ indicated statistical significance.

3 Result

3.1 Effect of 36 h TSD on Mental Rotation Ability

Under the conditions of 36 h TSD, there are obvious individual differences in the scores of TMRA, as well as considerable differences in individual spatial cognitive ability, as shown in Table 1.

Table 1. The average number of correct answers for 6 participants

	No. 1 participant	No. 2 participant	No. 3 participant	No. 4 participant	No. 5 participant	No. 6 participant
The correct number	50.47 ± 4.99	62.31 ± 2.62	67.64 ± 2.42	59.5 ± 3.92	58.44 ± 3.62	62.03 ± 2.86

By comparing the individuals' mental rotation scores, we find that during the 36 h TSD, the mental rotation scores of participants 2, 4, 5, and 6 have roughly the same trend over time, and the individual mental rotation test scores are analyzed as follows (Fig. 1):

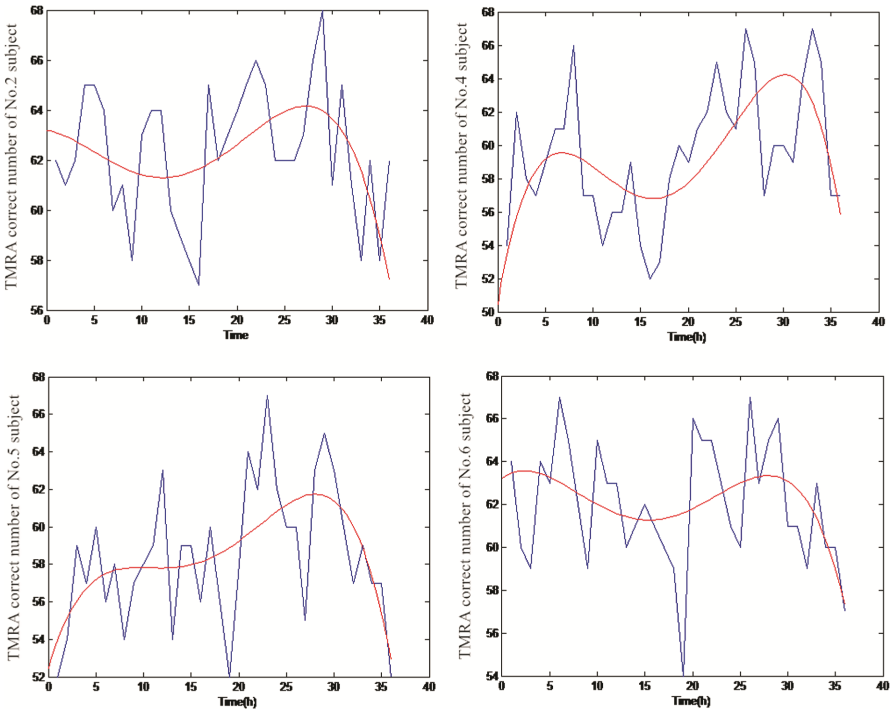


Fig. 1. TMRA scores distribution and fitting curve

During the first day (08:00 to 24:00) and the next day (00:00 to 19:00), the individuals' mental rotation performance generally showed an upward trend first and then a downward trend. At 23:00 on the same day and at 2:00 the next day the results reached a minimum.

The average answer accuracy rate of four participants during the 36 h TSD is shown in Fig. 2. In order to eliminate the effects of biological rhythms and other factors and keep the rhythm consistent, Take two days at the same time, four participants were compared the correct rate of mental rotation test. Four time points—9:00, 12:00, 15:00, and 18:00—were selected for comparison, as shown in Fig. 3.

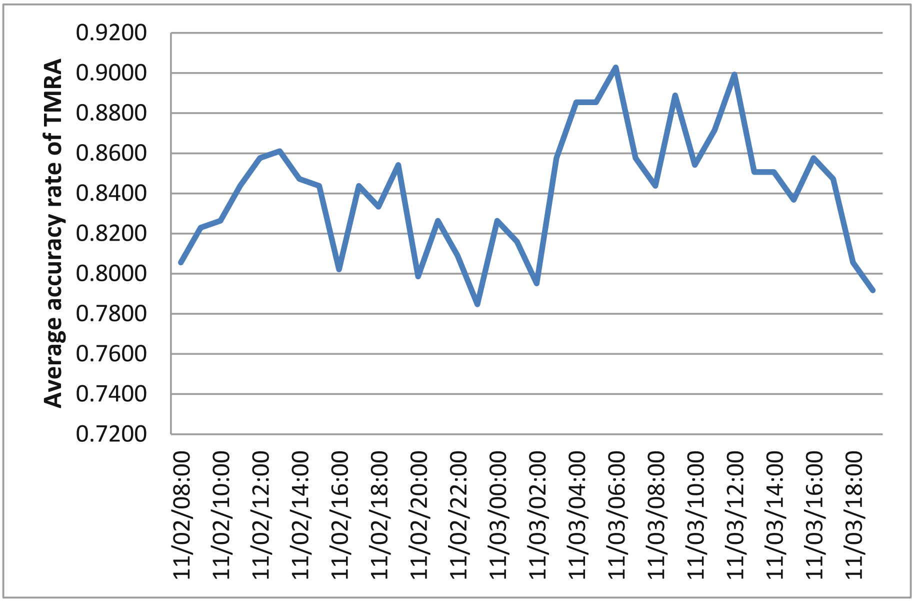


Fig. 2. Effect of 36 h TSD on TMRA average accuracy rate of 4 participants

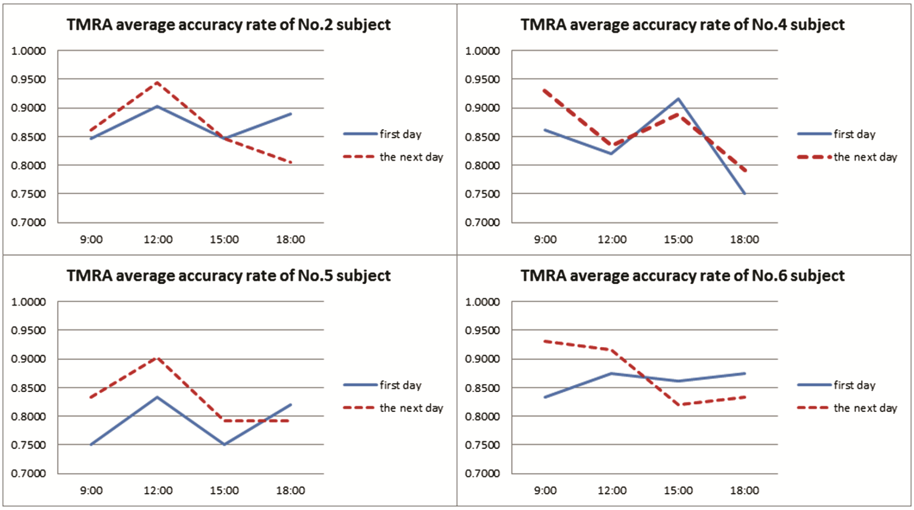


Fig. 3. Average accuracy rate of TMRA contrast

As shown in Fig. 2, the results of the mental rotation test show a pattern of first rising and then falling in a day's time, with performance reaching a minimum at 23:00 on the first day, and 2:00 the following day. As shown in Fig. 3, comparison showed that, excluding individual biological rhythms and other factors, the mental rotation test results of four participants are higher on the second day of sleep deprivation than those during the first day from 8:00 to 12:00. On the whole, during the 9:00 to 18:00 time period, the second day of sleep deprivation does not significantly decrease mental rotational test scores as compared with most of the corresponding time points on the first day. The results suggest that because of the large number of repetitions and simplicity of the test questions, the participants themselves became more and more familiar with the test questions. Consequently, there is no obvious declining trend during daytime hours, or on the second day compared with the first day.

3.2 Effect of 36 h TSD on Alertness

With the increase of 36 h TSD, the overall KSS score shows a fluctuating trend that is rising overall. The KSS score increases significantly ($p < 0.01$) at 13 :00, 14:00, 15:00, and 16:00 on the first day of the experiment, and 1:00, 2:00, 3:00, and 4:00, as well as at 13:00, 14:00, 15:00, and 16:00 on the second day, as shown in Fig. 4.

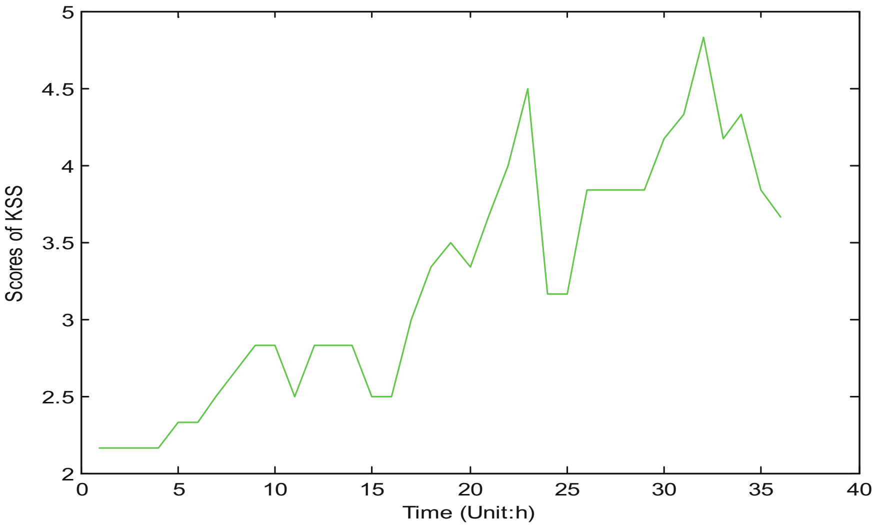


Fig. 4. Effect of 36 h TSD on the KSS scores

In this experiment,The KSS self-rating scores significantly correlated with the correct rate of mental rotation tests ($p < 0.05$). The KSS scores increase significantly from 23:00 on the first day, and begin to decrease from 6:00 the next day. The scores of the mental rotation test are at their lowest from 23:00 to 2:00 on the first day. Sleep deprivation can lead to a rising trend of alertness among normal youth. During the day, alertness scores had somewhat risen. These results suggest that the effects of circadian rhythms will offset some of the effects of sleep deprivation.

Correlations			
		KSS	Mental rotation test
KSS scores	Pearson correlation	1	.417*
	Sig. (2-tailed)		.012
	N	36	36
Mental rotation Test	Pearson correlation	.417*	1
	Sig. (2-tailed)	.012	
	N	36	36

*Correlation is significant at the 0.05 level (2-tailed).

Periodic increases in alertness are observed during TSD because of the effect of circadian rhythms. Circadian rhythm refers to the psychology and physiological functions of the human body that change over an approximately 24 h cycle. In the psychological function of the circadian rhythmic trough, alertness, perceptual ability, sustained attention ability, attention distribution and transfer ability, memory, speed of reaction, and thinking ability decline, while sleepiness increases and emotional aggravation is observed. Physiological rhythm causes the body's hormone secretion, body temperature and other physiological processes to show periodic changes with the circadian rhythm, resulting in the fluctuation of spatial operation and cognitive ability level, as shown in Fig. 5.

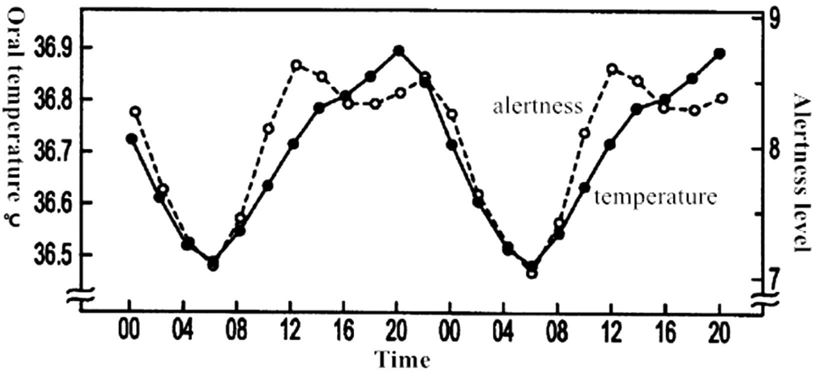


Fig. 5. The alertness and temperature vary with the rhythm.

4 Discussion

According to previous studies [8–10], TSD has less effect on physical ability and simple mental rotation ability, but has significant effect on complex mental ability. In relatively low-load tasks, physical-based, simple tasks, and tasks for which the individual is proficient are rarely affected by TSD, and more complex cognitive tasks are more affected by TSD. Cognitive tasks during simple visual search experiments show that the speed of completion of the task was significantly affected by the accuracy of little effect, showing rhythmic fluctuations over 48 h TSD [11]. Tests on visual scanning arousal state, selective visual reaction time, memory matching operation task, exercise learning and memory ability and emotional state showed that 72 h TSD and environmental stress significantly impaired the cognitive operation ability and emotional state [12]. Thomas's study has shown that lack of sleep for a week leads to a decrease in the speed of the psychomotor alert task test and an increase in errors [13].

In the present study, spatial cognitive ability is the essential psychological quality of most aviation workers. It is a central element to ensure completing the task safely and efficiency. And the 36-h TSD can affect cognitive ability and alertness to rhythmic fluctuations. However, research shows that TSD has less impact on simple mental work, the task of mental rotation is simpler than that of complicated mental work, and the repetition rate is high. Under the conditions of 36 h TSD, the damage to spatial cognitive ability does not change significantly, and the influence of repeated operation is not ruled out. In future studies, the complexity of mental tasks may be increased, the repeatability of experiments may be avoided, the number of participants may be enlarged, and the influence of TSD on cognitive ability, judgment ability, and operation ability may be further studied.

5 Conclusion

Conclusions are summarized as follows:

There are obvious individual differences in the spatial cognition of normal young people in a certain degree. Under the condition of 36 h TSD, the spatial cognitive ability of normal young people is decreased to a certain degree. Performance is the lowest between 23:00 on the first day and 2:00 on the second day. Because of the test simplicity and the number of repetitions, the learning proficiency of the test subjects has a certain impact on the mental rotation performance. As such, their scores on the mental rotation test during the daytime hours on the second day did not drop significantly as compared with those obtained on the first day. Thirty-six hour TSD causes a rhythmic fluctuation decline in the alertness of normal youth, however during the daytime hours the effects of sleep deprivation are offset by a rise in biological rhythms, restoring alertness.

Lack of sleep and circadian rhythms of the human body are important factors that affect aviation safety, will lead to alertness, perceptual ability, sustained attention ability, attention distribution and transfer ability, memory and speed of reaction decline, while sleepiness increases and emotional aggravation is observed. Therefore, to counter the adverse effects of TSD, corresponding measures should be taken when the time of TSD is long and occurs during the trough of individual biological rhythms. For flight crew members, sufficient rest and sleep should be performed before across time zones and long-range flight. And should be scientifically scheduled and arranged with a sufficient number of pilots. Crew members take turns napping for 40 min, helping to relieve fatigue and maintain endurance during the rest of the flight. After arriving in the destination, they should rest for a sufficient time to complete the rhythm reconstruction. For air traffic controllers, if they lack enough sleep, the possibility of fatigue will rise sharply, even asleep during work. Efficient schedules will rationalize resources and mobilize resources, so that controllers can have better rest. All the aviation staff should be scheduling to prevent fatigue, and put the fatigue risk management into practice.

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