The EEG changes during night-time driver fatigue

Xie Xiaoli[1], Hu Jiangbi[2], Liu Xiaoming[3], Li Pingsheng[4], Wang Shuyun[5]

1, 2, 5 Transportation Research Center, Beijing University of Technology
3 Beijing Municipal Committee of Communications
4 National Center of ITS Engineering & Technology
xxl@emails.bjut.edu.cn

Abstract

Driver fatigue is one of the main causes of traffic accidents. Many researchers believe that electroencephalography is very accurate and promising to detect driving fatigue, but so far, the research results have been variable. Through simulation experiments, this paper found when driving at night, delta band varies significantly with the degree of fatigue. The results have implications for real-time automatic detecting driver fatigue at night and are helpful for future development of driver fatigue countermeasures.

1. Introduction

Driver fatigue is no doubt harmful to traffic safety. While fatigue-related accidents are not a big part in all road traffic accidents, but they are much more serious than the others. Therefore, it is necessary to take a series of countermeasures to avoid driver fatigue accidents.

At present, there are three mainly categories of countermeasures: behavioral countermeasures, technological countermeasures and regulatory countermeasures. Behavioral countermeasures have little effect and any lasting restorative benefit; regulatory countermeasures are inflexible and their enforcement is costly and difficult; technological countermeasures' validity remains to be demonstrated (Laurence R Hartley, 2004). In these three categories of countermeasures, researches are focus on technological countermeasures, because they have some characteristics such as real-time and accurate, which can make the countermeasures more effective to avoid fatigue-related accidents. In technological countermeasures, many researchers believe that electroencephalogram (EEG) can reflect the state changes of driving fatigue accurately and can be used as a predictor.

EEG is a kind of spontaneous bioelectrical activity of brain, records from the electrodes of the EEG recording system, and is expressed in the form of curves which horizontal axis is time and vertical axis is potential. These signals don't have any meaning themselves. They must be analyzed, and then parameters, which can represent the individual's mental state, can be able to found. The general range of human EEG frequency is 0.5~30Hz, and is usually divided into four bands: alpha band, beta band, theta band and delta band. In previous studies, researchers have found that the changes of the four bands could reflect fatigue state of brain ([a]Saroj K.L. Lal, 2001).

In the early years, the researchers often used visual method to estimate the quantities of each kind of brain waves and determine whether a driver was fatigue. By this method, it is difficult to determine driver fatigue accurately, and as a result, EEG can not widely used in driving fatigue research field. In recent years, with the wide applications of computer and the development of signal processing technology, frequency domain analysis has become conventional analysis method in EEG analysis field. Through the Fourier transform, this method transforms the original EEG signal from the relationship between time and amplitude into the relationship between frequency and power or the relationship between frequency and amplitude, and then calculates the average or the area magnitude of each wave band. Finally, several quantitative parameters are developed. These indicators could quantify the functional state of central nervous system. Although the effect may not exceed the effect of visual EEG analysis, these indicators makes it possible to use EEG in driving fatigue monitoring.

However, after the technical problem, theoretical issues emerged. Most of these EEG indicators are not so satisfactory (Budi Thomas Jap, 2009). The indicators still can't used in practical application because their changes are not so large and it is not easy to distinguish their changes with fatigue level. By experiment study, this article found that delta wave, which was studied about not so much in the past, changed significantly during night-time driving simulation experiment, and can be used as a measure of driver fatigue state in real-time monitoring.

2. Experimental programs

2.1. Experimental protocol

In real world, it is dangerous for drivers to take part in driving fatigue experiments. In addition, EEG recording system has poor anti-jamming ability, so the requirements on collecting environmental are higher, while it is difficult to control the factors in the real environment ([a]Saroj K.L. Lal, 2001). Therefore, as the basis for follow-up study, this article used simulation experiment. If the findings are effective, in the future it can be verified in driving simulator or in real road environment.

Driving is a task composed of mental work and manual work. The volume of manual work is equal to the volume of

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general administrative work, while the volume of mental work is larger. Therefore, driving is a kind of sensory nerve task; driving fatigue is almost mental fatigue. Hence, mental fatigue research methods can be introduced into the study of driving fatigue. In the study of mental fatigue, the medical model of mental fatigue is very difficult to be set up, because there are many factors which may affect it. Therefore sleep deprivation is commonly used to set up the medical model of mental fatigue. This is because: firstly, the negative effects of sleep deprivation on human body are similar to the effects of mental fatigue, such as the level of operation reduced and alertness decreased; secondly, the controllability of sleep deprivation is larger, and the deprived time can be shorter or longer; thirdly, sleep deprivation is safe, and does not harm human physiological and psychological functions. Consequently, although the negative status of human physiological, psychological functions affected by mental fatigue are not equal to which affected by sleep deprivation, the latter is accepted as a special case of the former (Cao Xueliang, 2006).

Besides, fatigue-related accidents are often long-distance single vehicle accidents, mainly happened in the early morning. At that time, because the driver had a long working hours, plus driving at night, he/she could go to sleep very easily; at the same time, there were very few vehicles on the road, the visible information might also be significantly reduced due to the dark. In this case, there was a small amount of information for the driver to process, and the driving operations are very simple.

Accordingly, this paper used sleep deprivation method. The experiments were conducted during 0:00 to 6:00 and at the beginning of the experiment, all the participants had been awake at least 16 hours. The fatigue arising from this situation is considered as driving fatigue.

2.2. Independent indicators

Because fatigue can not be directly measured, it is necessary to introduce some indicators as independent indicators to quantify the extent of driving fatigue, which are recognized in a large scope and easy to control. However, many studies have overlooked the importance of independent indicators, and usually determine the extent of driving fatigue arbitrarily. In this way, the experimental results are unreliable. In this study, two independent indicators were used.

2.2.1. Subjective evaluation indicator

Most driving fatigue studies used subjective evaluation method. This article asked the subjects filled out self-reported fatigue level questionnaires (see table 1) according to their own subjective feelings. Zhao Changcheng (1992) had presented the questionnaire design principles and quantified methods. The quantified values were called subjective fatigue degree.

Compared with other methods, subjective evaluation methods is simple to conduct and can save energy, but is lack of objectivity. In order to ensure the reliability of scientific research, this kind of indicators should not be used alone, and some objective indicators need to be taken into account ([a]Saroj K.L. Lal, 2001).

Table 1 Self-reported fatigue level questionnaire

State / Level	Very alert	Alert	Not sure	Fatigue	Very fatigue
3					
2					
1					
-1					
-2					
-3					

2.2.2. PVT indicators

PVT (Psychomotor vigilance task) is a widely used standard test for the spirit response speed, which has better objectivity and reliability (National Highway Traffic Safety Administration, 1998). For driving fatigue measurement, PVT is suitable. Since the main requirement of driving task is response fast, and PVT is based on reaction time. Therefore, in the study of driving fatigue, it is appropriate to use PVT result as an independent indicator.

According to the principle of PVT, the paper programmed the test using Stim2 software of Neuroscan. The task for the participants is to button response to the visual signals showed in the middle of a black 17-inch LCD screen. The signal was a yellow round with a radius of 4 centimeters and the emergence was random from 2 to 10 seconds. Participants were asked to use his right hand (left-handed person left hand), and when the signal appears, press the mouse button as soon as possible. After the signal disappeared, the software will record the reaction time automatically. The task lasted 10 minutes. The length of the test and the data statistical method are various, but, once they are specified, PVT scores can be compared between different experiments.

In this paper, the number of the reaction time which was greater than 400ms (including the mistakes) of each test was calculated as an independent indicator, named as error numbers.

2.3. EEG indicators

The NeuroScan 36 channels EEG recording system was used to record the EEG, whose Ag/AgCl electrode cap are easy to wear. Thirty-two EEG channels were recorded following the International 10-20 Montage system and referenced to right ears and sampled at 1000 Hz covering the major areas of the brain.

Scan4.3 software was used to analyze EEG data. First of all, the recording reference was transferred to linked ears. Then the vertical ocular artifacts were removed. After that, spectral analysis was performed. The EEG data was defined in the following frequencies: delta (0.5-4Hz), theta (4-8Hz), alpha (8-13Hz) and beta (13-30Hz). These frequencies of every channel were extracted from the EEG data using fast Fourier transform (FFT). After that, the average EEG magnitude (in power) was computed as an average of the 32 channels (representative of the entire head).

2.4. Experimental procedure

Three young male participants who were licensed drivers were recruited in the study. They had an average age of 25. Before the experimental day, they all rested well. From 0

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o'clock, every 2 hours, all participants were asked to do the alert task once until 6 o'clock. Before each test, the participant worn the EEG electrode cap firstly, and then fill in the self-reported fatigue level questionnaire. Each participant was tested 4 times in total. In the course of the alert task, the EEG was recorded.

3. Data Analysis

Curve-fitting method was used to find the relationship between every indicators and test time. To diminish the effect of individual differences on the results of the fitting, this article fitted individual data separately. Fitting results are shown in Figure 1, 2, 3, 4, 5, 6 and Table 2.

From the results of curve fitting, it can be seen that most of the data fit well, especially the EEG indicators, whose changes with time are very obvious. No. 1 participant's EEG indicators' fitting curves firstly reduce and then increase during the whole experiment, and the lowest EEG magnitudes occur around 4:00. This trend is conforming to the trend of subjective fatigue degree. The fitting curve of error numbers increases gradually with time. No. 3 participant's subjective fatigue degree also reduce firstly and then increase, same as No.1, but the changes of each EEG indicators are different: the fitting curves of alpha and theta bands increase gradually; beta band magnitude nearly unchanged through the whole experiment; the fitting curve of theta band decrease significantly in the first and second test and then more or less unchanged. Error numbers increases gradually with time, same as No.1, but the slope is smaller. No.2 participant is entirely different from the others. His subjective fatigue degree increases with time, without inflection point. The error numbers of the first three tasks are nearly the same, while in 6:00 the curve increases sharply. As to the EEG indicators, the curves almost unchanged with time.

Due to individual differences, three participants showed different indicator changes, though the experimental conditions are same. After the feedback surveys, we can draw the following reasoning. The three participants had experienced different level of fatigue. The level of No.1 is the lowest, No.2 the highest, and No.3 in the middle of the others. When the level of fatigue is low, subjective feeling of fatigue is affected by the circadian rhythm greatly (shown in Figure 1), as well as EEG indicators. When the degree of fatigue increases, the impact of circadian rhythm weakened. The changes of EEG indicators can show this process obviously, especially delta band: the EEG indicators reduce to a certain level and then become stable (shown in Figure 3). When the fatigue level is high, the feeling caused by the experimental conditions will fully overlap the impact of circadian rhythm to fatigue feelings. At this time, the changes of EEG indicators are very small, actually stable. Error numbers didn't change a lot at the beginning, but when the participant was unable to bear the fatigue, the physical and mental state of participant reduced sharply and the performance is prone to mutation (shown in Figure 2). That is why fatigue-related accidents happened.

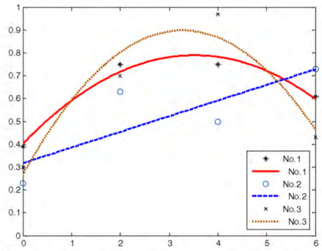

Figure 1 Subjective fatigue degree changes with time

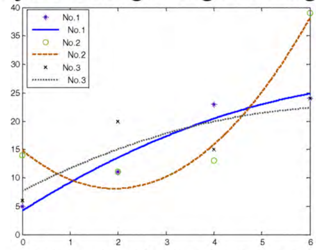

Figure 2 Error numbers changes with time

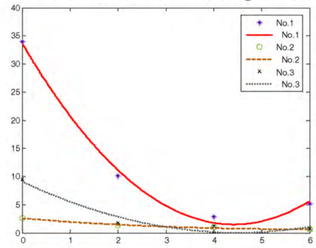

Figure 3 Delta band average magnitude changes with time

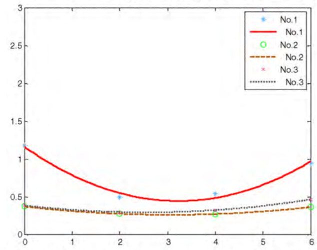

Figure 4 Alpha band average magnitude changes with time

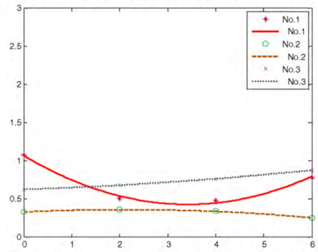

Figure 5 Theta band average magnitude changes with time

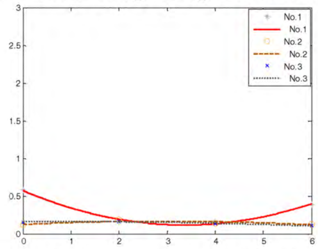

Figure 6 Beta band average magnitude changes with time

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Table 2 Curve fitting goodness of indicators changes with time

Indicators	Data	Type of fit	R-square	SSE
Subjective fatigue degree	No.1	Quadratic polynomial	0.97208	0.00242
	No.2	Linear polynomial	0.66710	0.04683
	No.3	Quadratic polynomial	0.91301	0.02312
Error numbers	No.1	Quadratic polynomial	0.94415	14.45
	No.2	Quadratic polynomial	0.96560	18.05
	No.3	Quadratic polynomial	0.69875	54.45
Delta band average magnitude	No.1	Quadratic polynomial	0.99602	2.44107
	No.2	Quadratic polynomial	0.98433	0.03581
	No.3	Quadratic polynomial	0.95204	2.47392
Alpha band average magnitude	No.1	Quadratic polynomial	0.98034	0.00644
	No.2	Quadratic polynomial	0.99974	2.40E-6
	No.3	Quadratic polynomial	0.99999	1.39E-9
Theta band average magnitude	No.1	Quadratic polynomial	0.98987	0.00240
	No.2	Quadratic polynomial	0.99898	6.50E-6
	No.3	Quadratic polynomial	0.99907	3.31E-5
Beta band average magnitude	No.1	Quadratic polynomial	0.98486	0.00187
	No.2	Quadratic polynomial	0.45293	0.00160
	No.3	Quadratic polynomial	0.96287	7.21E-5

From the above analysis, it can be preliminary drawn that from the four EEG indicators, delta band is more sensitive to driver fatigue than the others. So, the paper uses curve-fitting method to find the relationship between delta average magnitude and error numbers. The results are shown in Figure 7 and Table 3.

It was shown in Table 3 that the fit of No.2 was not good. That is because the data of No.2 fluctuate in small waves through all tasks, unlike the other two participants (shown in Figure 7). The slops of fitting line of the others are bigger. The results validate our reasoning: when the delta band average magnitude decreases to a certain extent, and maintains stable in a long period of time, the individual is already in a state of fatigue, if he/she continues driving, the possibility of traffic accidents are higher.

From the above analysis, this article finds delta band average magnitude decreases with the increase of fatigue level. In previous studies, because delta band is easily overlapped by artifacts, few researches took delta band into account. In a small number of studies (such as [b]Saroj K.L. Lal, 2001 and Nirupama Wijesuriya, 2007), delta band activity increases with the increase of fatigue level. This paper believes that this difference is due to the different experimental conditions shown in Table 4. The significantly different experimental conditions results in different conclusions. In the future study, the same experimental conditions should be used, so that the results can be compared among different studies.

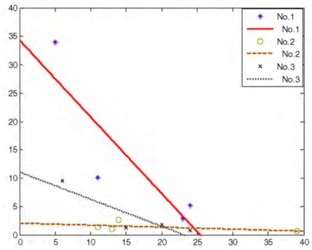

Figure 7 Delta band average magnitude changes with error numbers

Table 3 Delta band average magnitude changes with error numbers curve fitting goodness

Data	Type of fit	R-square	SSE	Adjusted R-square
No.1	Linear polynomial	0.77126	140.320	0.65690
No.2	Linear polynomial	0.30037	1.59969	-0.04943
No.3	Linear polynomial	0.80355	10.1337	0.70533

Table 4 Experimental conditions contrast

Experimental conditions	This study	Previous studies
Experiment time	Before dawn	morning、noon or afternoon
Participant	16 hours awake before test	Rest well or a little lack of sleep
Testing time span	6 hours	1 or 2 hours
Number of EEG recording channels	32	12, 19 or less
Delta band width	0.5-4Hz	2-4Hz

The paper also explores some physiological theories for the conclusion. In the EEG spectrum analysis, delta band is the dominant band in the normal human EEG. The main components frequency of delta band are similar with heart rate, so delta band may be associated with blood supply, and therefore, is likely to be a reflection of the process of nutrition of brain (Feng Quangen, 1986). When participants do not feel tired, delta band remains the normal level. When the level of fatigue increases, the brain is lacking of nutrition because of blood supply shortage, so the activity of the brain is becoming lower and lower. The evidence is that the magnitudes of all

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EEG indicators become smaller. Due to delta band is the dominant band, its changes are more obvious than the others.

4. Conclusion

EEG indicators are sensitive to the changes of fatigue level, especially the delta band. The delta band decreases rapidly with the increase of fatigue degree. when the average magnitude of delta band goes down to a certain extent and maintain stable in a long period of time, the driver is fatigue and not suitable for driving.

Due to the differences among people, the same conditions may cause different degree of fatigue. This is the reason for not trusting to luck. The education about driver fatigue should be enhanced.

This article is only a qualitative study. It needs a large number of experimental studies to get a specific threshold of delta wave indicator. The results of this research have the implication for detecting night-time driver fatigue, which will be helpful for future development of driver fatigue countermeasure devices, which can reduce fatigue related accidents and greatly impact the transport industry in terms of socio-economic benefits.

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