On-Road Influence of Driving Fatigue, Mental Workload on Drivers' performance

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Abstracts: Drivers' fatigue influence on driving secondary task, physiological indices, and subjective mental workload (MWL) were investigated between two different driving times in a day in real-road condition. Ten taxi drivers were required to do verbal arithmetic calculations while driving their cars in the morning and in the afternoon, respectively. Performance of secondary task, physiological indices, subjective MWL and subjective feeling of fatigue were compared. Difference of calculation deviances was significantly found, with more errors in the morning than in the afternoon. Physiological indices also showed different results. The other two subjective measurements were also compared. The results shows practice effect during driving. The study may have implications for technological countermeasures for driving figure.

Key Words: driving fatigue, secondary task, mental workload, physiological index

1 Introduction

Driving fatigue is one of the fatal factors to deteriorate the driver's performance and compromise road safety (Grandjean 1979; Lal and Craig 2001; Ting, Hwang et al. 2008). For instance, an increase of fatigue impairs drivers' cognitive skills (Brown 1994), causes higher changes of physiological indicators (Campagne, Pebayle et al. 2004; Eoh, Chung et al. 2005; Otmani, Pebayle et al. 2005), disrupts distance keeping and hazard avoidance in prolonged driving (Hulst, Meijman et al. 2001).

Many factors have contributions to fatigue in researches to date, such as monotonic, repetitive environment, driving duration, sleep deprivation and circadian rhythms, etc. For example, monotony of driving environment causes more frequent large steering wheel movement, vigilance decrement and greater fatigue (Thiffault and Bergeron 2003). Subjective ratings of drowsiness, eye blink frequency and duration, microsleeps, and steering-wheel inputs were found as a function of time-on-task (Nilsson, Nelson et al. 1997; Summala, Hakkanen et al. 1999). With sleep deprivation, researcher found that driver's drowsiness caused EEG changes before and after car accidents (Eoh, Chung et al. 2005). Circadian disruption and sleep disorder can also lead to reduced waking alertness, impaired performance, worsened mood and fatigue (Brown 1994; Lenne, Triggs et al. 1997; Lal and Craig 2001; Otmani, Pebayle et al. 2005).

The present study is primarily aimed to examine the relationship between drivers' fatigue and their driving performance in two different times in a day. It is hypothesized that the drivers' fatigue and its affects may be different in the morning with those in the afternoon. All participants are day-shift taxi drivers, who start work in the morning and stop the routine in the evening. It could be expected that participants are vigorous in both mental and physical states in the morning, and so lower fatigue and higher performance. Conversely, both states were poor in the afternoon, and so higher fatigue they feel and impaired performance. In terms of this logic, it is available to make a comparison of the fatigue and its influence on driving performance between two different times in a day.

In our study, fatigue was measured by a subjective feeling scale, and the driving performance was measured through the performance drivers finished a secondary task, an oral arithmetical calculation. Except for performance of secondary task, the main indices affected by fatigue also included physiological indices, subjective mental workload.

2 Methods

2.1 Subjects

Ten taxi drivers participated in the present experiment, aged 33-39, who had driven for 7-14 years with more than 600,000 – 1,200,000 km, and all were in good health. They were paid for participation. All were asked to drive their own cars during the experiment. All subjects haven't taken part in such experiments.

2.2 Materials

The traffic route is pre-specified in Beijing, and piloted with one moderator before the experiment. It owns a stable traffic and about one-hour driving distance, which is good enough for our experiment.

The secondary task was arithmetic addition, which was presented by digital recorder with a voice of a female mandarin at stable and slow speed. It included 270 items, and would last 60 min, which is almost as long as driving in the experiment).

The physiological signals were acquired by a Multi-parameter physiological signal detection device (KF-2). NASA-LTS was used to collect drivers' mental workload evaluation, and a revised questionnaire for subjective assessment of drivers' feeling of fatigue. Participants' oral arithmetic calculations were recorded by a portable recorder and an electronic watch was used to record and synchronize all the time devices.

2.3 Procedures

Two different day times were of interest for our experiment, in the morning and in the afternoon. To guarantee the different fatigued state between morning and afternoon, the morning section began on 9:15a.m., when the drivers were in good mental and physical state after one night's rest; while the afternoon section began around 3:15p.m., when drivers keep driving in the midday to be not as vigorous as in the morning. Every time the experiment lasted about one hour.

There are one master experimenter and two assistants to assist one driver's experiment. The master experimenter was responsible for fixing KF, explaining instruction, reminding the participants of the route and keeping records during the driving; one assistant recorded the participant's performance in distraction task, and the other recorded the driving process, such like the time to arrive at a road sign, the duration for waiting traffic lights. The experiments were conducted on weekdays for two weeks.

The procedure is presented as the following figure 1:

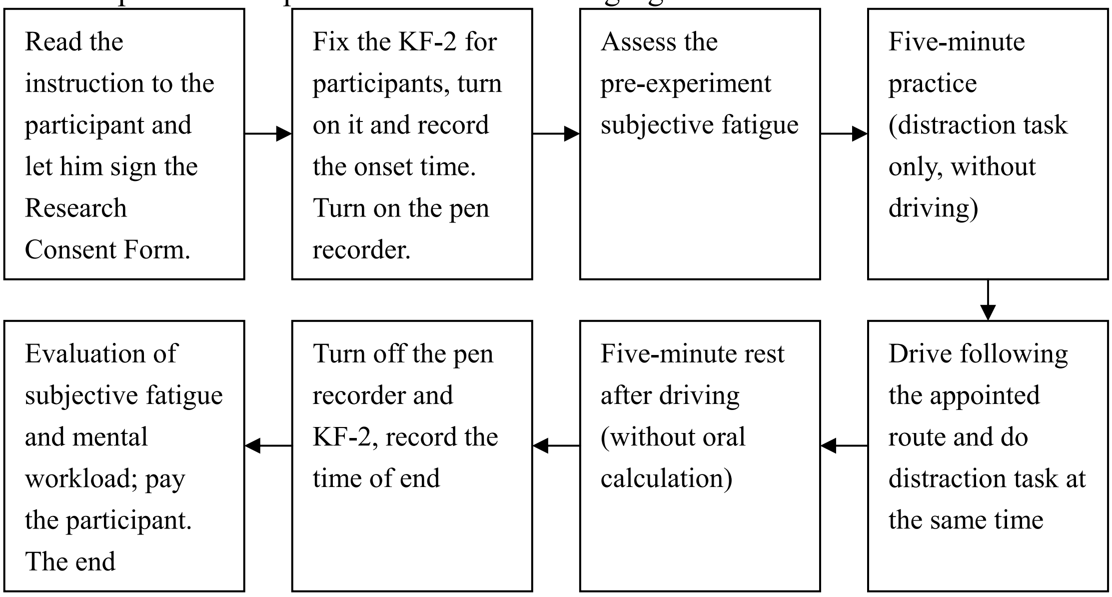

Figure 1. Flow of experiment process

3 Results

The performance of each participant in the secondary task was involved in analysis, with those erroneous data resulted from the problems of equipments deleted. All the data are averages between ten participants.

3.1 Response Time in Secondary Task

The results of the ten participant's reaction time and error rate in two different day times are presented in Figure 2.

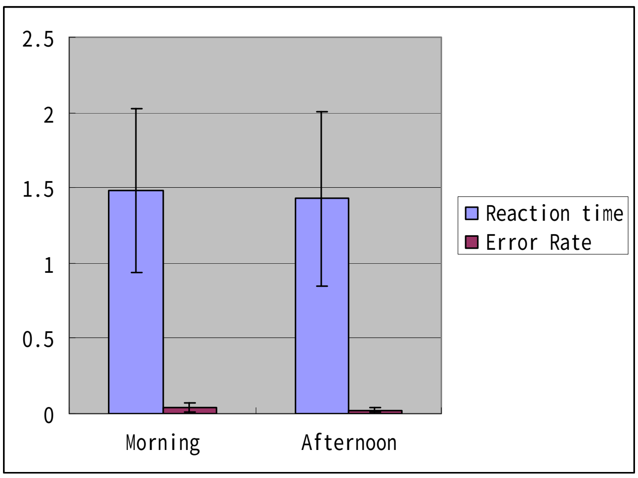

Figure 2. Error rate was significantly different between morning (4%) and afternoon (2.5%), with much higher error rate in the morning than in the afternoon (tdf=9 = 2.908**, Sig = 0.017). no statistically significant difference was found in reaction time, T-test ($t_{df=9}$=0.855, Sig = 0.414) showed the reaction time was longer in morning (1.482ms) than in afternoon (1.428).

3.2 Physiological indices

Four main indices recorded by the detector were involved in analysis. They were heart rate (HR), heart rate variability (HRV), breathe rate (BR), breathe rate variability (BRV), which is the sum of the difference between maximum and minimum breath rate of each minute, i.e., brv = $\sum(br_{max} - br_{min})$. The results are shown in Figure 3.

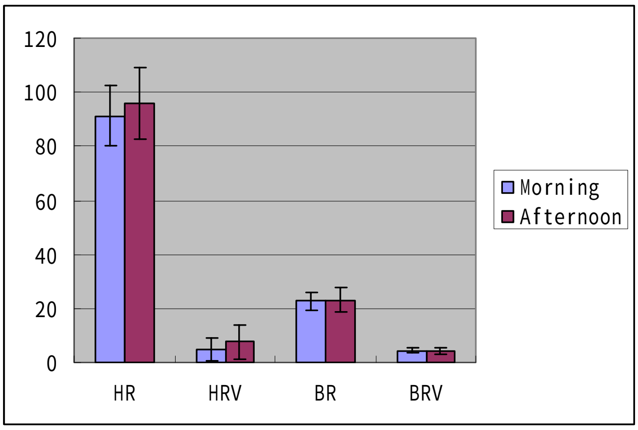

Figure 3. Marginally significant difference was found in the HRV (tdf=9 = 0.074) between two different day times ($HRV_{morning}$ = 5.025, $HRV_{afternoon}$ = 7.538). No significant differences were found in other indices (HRam = 91.288, HRpm=95.875; BRam=22.765, BRpm=23.213; BRVam=4.293, BRVpm=4.418).

3.3 Subjective Evaluation

3.3.1 Mental workload

Each time, when finishing the task, participants were required to evaluate MWL, using NASA-TSL. The results of descriptive statistic and t-test for MWL indicated that the difference was not significant, as shown in Table 1, but it was mildly higher in the afternoon than that in the morning.

Table 1 Comparison of MWL between morning and afternoon

	Mean	Std	t	df	Sig
Morning	124.418	44.673	-1.418	9	.19
Afternoon	145.97	58.253			

3.3.2 Questionnaire of Fatigue

Drivers' fatigue states were shown on figure 4. Significant difference was found between pre-test and post-test in the afternoon, and was found between post-tests in the morning and in the afternoon. Other comparisons were not significant.

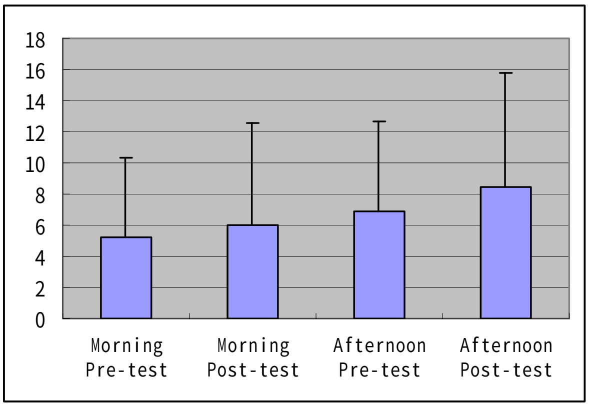

Figure 4. Marginally significant difference ($t_{df=9}$ = -1.922, Sig = 0.087) was found between pre-test (Mean = 6.9) and post-test (Mean = 8.5) in the afternoon, and so between post-test ($t_{df=9}$ = -1.838, Sig = 0.099) in the morning (Mean = 6) and in the afternoon (Mean = 8.5). There is no significant difference between morning-pre-test and morning post-test, and that between morning-pre-test and afternoon pre-test.

Table 2 and 3 shows the analytic results after converging the fatigue data in the morning and in the afternoon, and those of pre-test and post-test respectively.

Table 2 Comparison of fatigue between two times

	Mean	Std	t	df	Sig
Morning	5.625	5.28	-1.888	9	.092
Afternoon	7.7	6.455			

Table 3 Comparison of fatigue between before and after driving

	Mean	Std	t	df	Sig
Before	6.075	5.129	-1.056	9	.319
After	7.25	6.588			

It was implied that the self-reported feeling of fatigue in the morning was different from that in the afternoon in a certain extent, with more fatigued in the afternoon than in the morning. At the same time, the feeling of fatigue was stronger after experiment than before, but still insignificant in statistics.

4 Discussions

Fatigue affects on driving performance were examined on two different times in a day. In this part, we will first discuss the results which are in accordance with our expectation, and then the results which not.

Heart rate variability (HRV) showed difference between two times, with much higher HRV in the afternoon than that in the morning. Harris (1972) reported that changes in HRV and fatigue was associated with driving deterioration (Lal and Craig 2001). It seems that HRV can be served as another valid indicator for driving fatigue, while EEG was found to be a valid measure for physiological vigilance level for driving (Macchi, Boulos et al. 2002; Campagne, Pebayle et al. 2004; Eoh, Chung et al. 2005; Otmani, Pebayle et al. 2005). As for other physiological indices, there are should be more experiment to testify.

While specifying the driving route, controlling the driving experience, taxi drivers showed different subjective fatigue ratings between in the morning and in the afternoon. This is not surprised. Lenne (1997) found that some aspects of driving performance and subjective mood are subject to diurnal variations. And furthermore, Lemke (1982) concludes that subjective reports were more consistent and clearer than any of the variables derived from physiological measures (Nilsson, Nelson et al. 1997).

In our study, actually, performance in secondary task didn't conform to our expectation in terms of reaction time and error rate, which implies that taxi drivers were not in worse state in the afternoon than in the morning when dealing with the secondary task. These results may be constrained by two reasons. First, taxi drivers were not familiar with the second task although there were just 5 minutes for practice in the morning. They were well adapted to the arithmetic calculation to gain good reaction time and lower error rate in the afternoon. This can be explained as practice effect. Second, the driving behavior on road was self-paced because of traffic safety, which may offset the performance of secondary task(Brown 1994). In the same way, why mental workload (NASA-TSL) didn't show what we expected also can be contributed to practice effect and self-paced driving, so that the attentional resources to finish the dual-task is enough(Desmond and Matthews 1997; Lal and Craig 2001).

5 Conclusions

Secondary tasks can be used as an indicator for measuring driving performance, such like reaction time and error rate in arithmetical calculation. HRV as physiological index was found different between two times in a day, which entails higher consistent with EEG as in empirical researches. Subjective evaluation, especially fatigue rating, gave more stable examination for our hypothesis. The results may have implications for technological countermeasures for driving figure.

6 Acknowledges

This work was supported in part by the National Natural Science Foundation of China (Grant No. 30670701). Correspondence concerning this article should be addressed to Kan Zhang, Institute of Psychology, Chinese Academy of Sciences, Beijing, China, 100101.

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