The effect of secondary task on driving performance, physiological indices and mental workload: A study based on simulated driving

Yan Ge [1, 2], Xianggang Xu[1, 2], Jing Li[1, 2], Xiuling Lu [1, 2], and Kan Zhang[1]

[1] State Key Laboratory of Brain and Cognitive Science, Institute of Psychology, Chinese Academy of Sciences, Beijing 100101, China, PH(86)010-64851104, FAX(86)010-64837182, Email: gey@psych.ac.cn;
[2] Graduate University of Chinese Academic of Sciences, Beijing, 100049, China

Abstracts: In this study, simulated driving program was adopted to get the effects of secondary task and driving experience on driving performance, physiological indices and subjective evaluations of mental workload (MWL). The results showed that the difficulty of secondary task influenced driving performance, physiological indices and MWL. The drivers' mental workload increased and driving performance decreased along with the increase of secondary task's difficulty. Physiological indices reflected drivers' tension, which could be used as effective indices of monitoring drivers' condition. Besides, experience also influenced driving performance. This study provided academic support for developing devices monitoring drivers' physiological and psychological conditions.
Keywords: Secondary Task; Driving Performance; Physiological indices; MWL

1 Introduction

Driving safety was a problem which was focused on by governments, institutes and vehicle companies. It's not only related to drivers' skill and awareness, but also related to drivers' condition. Except the technological factor of car itself, drivers' fatigue and mental workload were main reasons for traffic accidents. So, if some devices can be applied to monitor drivers' condition without affecting their driving behavior, supplying the drivers' driving condition of the time to reflect their fatigue and MWL, its prompt feedback may provide safety to the drivers. Therefore, this study explored the probability of using physiological indices as feedback of different driving conditions, which provided academic support for developing driving condition monitoring devices.

Distracter was the technology used mostly in driving study. Several studies have found that Cell-phone call（Strayer & Johnston, 2001）, tuning CD, operating navigation system, working memory tasks (Alm & Nilsson, 1995), mental arithmetic tasks (Harbluk, Noy, & Eizenmann, 2002; McKnight & McKnight, 1993) disturbed driving performance. Our study attempted to use mental arithmetic task as secondary task to explore the effect of secondary task on driving condition.

Driving experience was another factor, which influenced driving safety. Some researches showed that accident rate of new drivers were much higher than that of drivers who had many years of driving experience. Research of eye movement implicated novice driver can't search in a wider field of vision because of little experience, they were unable to detect risk in time（Peter Chapman, etc, 2002；Geoffrey Underwood, 2002）. So, driving experience was another explored factor.

Driving condition include three aspects in this study: behavior indices, physiological indices and psychological indices. Simulated driving program were used to supply several behavior indices, such as lane keeping, speed, following distance, reaction time to leading car events, etc. In physiological indices aspect, ERP was the reasonable choice for monitoring fatigue condition（Eoh et al.，2005）, but it can't be used on real car driving now, so we considered to use other index instead. Some research showed Heart Rate Variability (HRV) was an index which reflected fatigue condition during driving (Li et al., 2003), Heart Rate (HR) reflected information processing difficulty of driving. In this study, Multi-parameter physiological signal detection device (KF-2) was used to test HRV, HR, Breath Rate and body station, provided data support for monitoring driver's physiological condition. Besides, NASA-TLX scale was used to survey driver's metal workload in dual-task condition.

A 3 (Secondary task's difficulty)×2 (Driving experience) two-factor mixed experiment design was applied to get the effects of secondary task and driving experience on driving performance, physiological indices and subjective evaluations of MWL.

It could be hypothesized that the driving performance, physiological indices and subjective evaluations of MWL would be affected by driving experience and the difficulty of the secondary task. And there would be interaction between the two independent variables.

2 Methods

2.1 Participants

43 drivers (23 experts vs. 20 novices) participated in this experiment. The experts were those who had driven more than 3 years and over 20,000 km, while the novices were those who just got their licenses with little driving experience. 22 were males, and 21 were females, aged from 20 to 37. The average was 28.6 years (SD=4.9). Latin square design was implemented to counterbalance potential order effect and learning effect.

2.2 Materials and equipments

Driving simulator: Participants drove in a middle-fidelity, PC-based driving simulator. Five visual information channels were displayed on one 17-inch Samsung monitor (1024×768 pixels): windshield view, speedometer, and left, right and center rear-view mirrors. A non-force-feedback Saitek R220 USB steering wheel, coupled with accelerator and brake pedal, was used to control the vehicle.

Secondary task: Secondary tasks were auditory mental arithmetic tasks, in easy-secondary task subjects were asked to perform two-digit plus one-digit addition counting (60 items) and in hard-secondary task subjects were asked to perform two-digit plus two-digit addition counting (60 items). They were presented by digital recorder with a voice of female mandarin at a speed of 2-3 characters per second (edit with Gold Wave 5.14 Chinese Version). The duration of each item was ten seconds. The content of the item was presented in the first three seconds, and the last seven seconds were blank for the participants to respond.
Multi-parameter physiological signal detection device (KF-2): It was used to record heart rate variability (HRV), heart rate (HR) and breathe rate (BR).

2.3 Procedure

At the beginning, we introduced this experiment to the participant, let him/her sign the Research Consent Form, and then fixed the KF-2.

There was a 10-minute training stage before formal blocks. The participants should follow the leading car, keep in the same lane with it and maintain appropriate distance. If the distance was too close (closer than 8m to the leading car), the speedometer in the lower right corner would flash to remind participants of the collision to the leading car. When the turning lights of the leading car flashed, participants should press the button of the corresponding side on the steering wheel to respond, and followed the leading car to change lane.

Formal experiment included three blocks: no-, easy-, and hard- secondary task block. They were balanced by Latin square design to present to the participants. While doing the simulated driving task, participants should listen to the calculating items through the earphone, and report the answer aloud to the microphone. In the driving part, the simulation system recorded the driving performance indices automatically. The reaction time and accuracy of pressing button when the special incidents such as turning happened in the following task were also recorded. Participants would finish one NASA-TLX Scale after each block, and then they could take a break before next block.

3 Results

40 effective data were received at last [expert=20(male=10, female=10), novice=20 (male=11, female=9)]. All descriptive statistic results were showed in table 1.

3.1 Secondary task

39 effective data were received in this part. The accuracy of one-digit mental arithmetic task (rate=0.935, SD=0.098)was much higher than that of two-digit (rate=0.817,SD=0.143), t=6.045, df=38, p<.001. The RT of one-digit mental arithmetic task(RT=1441.716ms, SD=496.207) was faster than that of two-digit （RT=2068.280ms, SD=559.948）, t=-9.044, df=38, p<.001. It was obviously that one-digit mental arithmetic task was easier than two-digit.

3.2 Driving performance

Driving performance included several indices as below:

Collision number: When the distance between the leading car and the following car which was controlled by participant was less than 8m, one collision would be recorded. Table 1 showed descriptive statistics results of collision numbers. Repeated measures of General Linear Model were used to analyze data. There was marginally significant difference in collision numbers among difficulties, F=3.015， p=0.062. Experience has no significant influence, and no significant interaction was found. It prompted that the collision numbers increased along with the increase of secondary task difficulty. Pairwise comparisons were used to compare collision numbers in three different difficulties. Collision numbers of no-secondary task was significantly less than that of easy- secondary task and hard-secondary task. It's obvious that secondary task disturbed driving performance of participants.

SD of following distance: Following distance was the distance between the leading car and the following car, SD of following distance was the change range of the average of following distance. If SD of follow distance was smaller, it illuminated participants control the car better. F test showed the difference of SD of following distance was significant, F=7.503, p<.001. Participants control car worse along with secondary task's difficulty increasing.

Reaction to events: This is the reaction of pressing button when turning lights of the leading car flashed. Accuracy rate and reaction time to events were showed in table 1. There was very significant difference in accuracy rate (F=9.627， p<.001) and RT (F=6.124， p<.01) among different difficulties. Accuracy rate descended and RT increased along with the increase of task difficulty, there was no trade-off between accuracy rate and RT. Experts react faster than novices, F=4.086， p=.051. Fig 1 showed the difference clearly. Reaction time of novices was longer than that of experts. It suggested that novices were easier to be disturbed by secondary task.

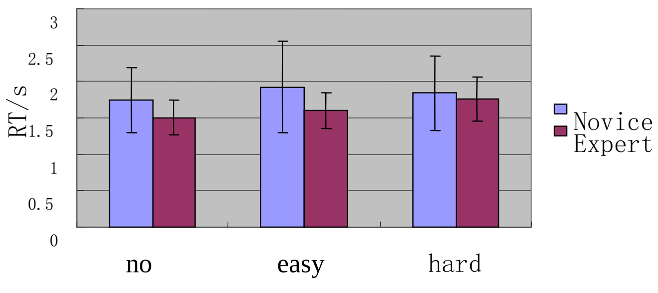

Fig.1 Reaction time to events between novice and expert

3.3 Physiological indices

Heart Rate Variability (HRV): It was the ratio of LF（0. 04～ 0.15 Hz）and HF（0.15～ 0.4 Hz）. The main effect of secondary task's difficulty on HRV was very significant, F=7.191， p<0.01. There were significant differences between each two conditions. It indicated that HRV increased along with difficulty increasing.

Heart Rate (HR): Significant difference was found in HR among different difficulties, F=18.111, p<0.001.

3.4 Subjective evaluation of mental workload

NASA-TLX rating scale included six dimensions: mental demand, physical demand, time pressure, performance satisfaction, effort and frustration. The scores in the six dimensions were weighted by 3.7, 1.3, 3.0, 2.7, 3.2, and 1.3. The analysis on MWL was based on the average of weighted score. Average weighted score in different condition were showed in table 1. Repeated measures analysis of MWL revealed a significant main effects of secondary task's difficulty, F=106.873, p<0.001. Participants thought MWL increased along with secondary task difficulty increasing.

Table 1 Descriptive statistic results of all dependent variables

	No-secondary task		Easy-secondary task		Hard-secondary task	
	Mean	SD	Mean	SD	Mean	SD
Collision number	18.47	21.747	22.68	25.865	29.2	35.842
SD of following distance (m)	8.999	2.592	9.772	2.951	10.498	3.523
Accuracy of reaction to events	0.802	0.259	0.759	0.284	0.713	0.26
Reaction time to events(s)	1.626	0.37	1.762	0.497	1.803	0.416
HRV	1.743	1.207	2.089	1.378	2.524	1.631
HR	75.538	9.299	78.282	9.919	79.615	10.599
NASA-TLX	9.046	2.31073	11.1906	2.53107	12.8952	2.42611

4 Discussions

For driving performance, collision number and SD of following distance increased along with the increase of secondary task's difficulty, while driving experience had no significant influence on them in this study. It illuminated that secondary task disturbed performance of primary task, it added extra mental workload to drivers, so their awareness of vehicle control decreased, and driving performance in veracity was also reduced. In reaction to events, accuracy rate decreased and RT increased along with task difficulty increasing. Reaction of novices was slower than that of experts. These prompted experts were more skilled in driving cars. They drove better than novices in dual tasks.

For physiological indices, HRV, HR increased along with the secondary task's difficulty increasing. As the secondary task's difficulty increasing, sympathetic nerve acted actively, participants became more intense, and heart beat quickly. Therefore, HRV and HR were sensitive indices for secondary task difficulty. They showed physiological state in different task state and mental workload, which could be used to monitor drivers' physiological and psychological state instead of ERP.

For mental workload, average of weighted score increased along with task difficulty increasing, it illuminated that MWL was influenced by secondary task's difficulty. This was coherent with results of driving performance and physiological indices.

5 Conclusions

In a word, difficulty of secondary task influenced driving performance, physiological indices and mental workload. Secondary task added extra information processing workload. So, participants' primary task performance was disturbed, physiological indices were also influenced. HRV and HR could be considered as indices for monitoring drivers' condition. Besides, experience influenced driving performance in reaction to events. Experts responded faster in events reaction, but no significant difference in physiological indices and subjective mental workload was detected between novices and experts.

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