The Measurement of Driver's Mental Workload: A Simulation-Based Study

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Abstract: Many of the road accidents can be attributed to driver failures. Mental workload was an effective index of drivers' status, so measurement of driver's mental workload is significant to improve the driving safety. In this research, four types of measurements were adopted to measure the driver's mental workload on different road types and with presence or absence of the secondary task. The results showed that the combination of responses to the critical event of the leading car, heart rate and subjective mental workload rating was an effective approach to measure drivers' mental workload in this situation. Actual or potential applications of this research include developing driver status monitoring or warning system and developing an effective technique to evaluate driver distraction.

Key words: *driving safety, mental workload, measurement*

1 Introduction

Driving a vehicle may seem to be a fairly simple task. After some initial training many people are able to handle a car safely. Nevertheless, accidents do occur and the majority of these accidents can be attributed to human failure. The factors which can affect the driver safety could be categorized into two groups. One is driver status-related factors, such as: fatigue, drowsiness, alcohol, driving experience, age, and so on; the other is driving task related factors, such as traffic, road type, complexity of distraction task, and so on. The above-mentioned examples have in common that in all cases driver workload is affected.

Workload is a demand placed upon humans. The importance of research on mental workload lies in two aspects. The assessment and comparison of workload imposed by equipment, could be used to optimize the system; the assessment of workload experienced by the human operator, could be used to select the operator or provide them further training. The measurements of mental workload may be classified into four categories: primary-task measures, secondary-task measures of spare capacity, physiological measures, and subjective rating techniques (Wickens, 2000). O'Donnell and Eggemeier (1986) propose some criteria that should ideally be met by any technique to assess mental workload: sensitivity, diagnosticity, selectivity, obtrusiveness, bandwidth and reliability.

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The aim of this research was to evaluate the effects of driver experience, road type and secondary task on driver's mental workload on a pc-based simulator, and examine the sensitivity and reliability of different kinds of mental workload indices.

2 Method

2.1 Participants

Twenty drivers participated in the experiment (10 male, 10 female). Participants 'ages ranged from 23 to 41 years (M=29.05, SD=5.83).Ten participants were experienced drivers (with driving experience more than 3 years and mileage more than 20,000 km) and ten were novices (with driving experience less than 1 year). All had normal or corrected-to-normal visual acuity.

2.2 Apparatus

A PC-based simulator was used in this research, which included a desk-top computer, a 17-inch monitor with resolution of 1024×768, a joystick (with wheel, gas and brake pedal) and driving simulation program. Another desk-top computer was used to present arithmetic via earphone to participants, and record reaction time and accuracy of participants' answer to arithmetic. A physiological signal recorder was used to record the physiological signal (HR, HRV, etc.) during the whole procedure.

2.3 Design and Procedure

The experimental design had one between-subjects factor: driver group (experienced drivers, novice drivers), and two within-subjects factors: secondary task (with-secondary task, without- secondary task) and road type (straight road, curved road). Car-following paradigm was used, in which the lead vehicle decelerates unexpectedly while the driver is engaged in a secondary task (Brookhuis, 1994), the secondary task was an arithmetic task (Brookhuis, de Vries & de Waard, 1991).

Each participant completed five blocks (including one training block), lasting 50 minutes (10 minutes each). The order of the blocks was manipulated according to a Latin square design so that potential order effects were counterbalanced.

The participants were instructed to follow the leading car, keeping close but safe distance. There were four kinds of events of leading car: acceleration, deceleration, left turn and right turn. When secondary task was presented, participants were instructed to give the answers loudly while driving. After each block, drivers completed NASA-TLX (Hart & Staveland, 1988), to rate the subjective mental workload.

3 Results

Four categories of data were analyzed: car-following performance, secondary task performance, physiological indices and mental workload subjective rating. The data were analyzed using SPSS 12.0 and repeated measures were applied to compute analyses of variance (ANOVA). Only statistically significant results (α=0.05) were reported here.

3.1 Car-Following Performance

Car-Following performance included: Mean and SD of car-following distance, Mean and SD of lateral position (to the center-line of the leading car), Accuracy Rate and Reaction Time of reaction to the critical events (which refers to the response to the leading car's left turn or right turn signal light).

SD of car-following distance The SD of car-following distance of straight road (M=11.687) was significantly larger than curved road (M= 8.560), $F(1,18) = 4.794$, $p= 0.042< 0.05$.

Mean of lateral position Main effect of Road Type was significant, $F(1, 18) = 48.870$, $p = 0.000 < 0.05$, curved road was larger (M=0.835) than straight road (M=0.705).

SD of lateral position Main effect of Road Type was significant, $F(1,18) = 67.061$, $p = 0.000 < 0.05$, interaction between Road Type and Secondary Task was significant , $F(1,18) = 4.523$, $p = 0.048 < 0.05$, further simple effects tests revealed that Only under the condition of With-Secondary Task, there was significant difference between curved road and straight road (Curved Road > Straight Road).

Accuracy Rate of the responses to the critical events Main effect of Road Type was significant, $F(1,17) = 10.900$, $p= 0.004< 0.05$, Straight Road (M=0.975) was higher than Curved Road(M=0.941); Main effect of With and Without-Secondary Task was significant, $F(1,17) = 5.226$, $p= 0.035< 0.05$, Without-Secondary Task (M=0.978) was higher than With-Secondary Task (M=0.938).

Reaction Time of the responses to the critical events Main effect of Road Type was significant, $F(1,17) = 12.318$, $p= 0.003< 0.05$, Straight Road (M=1.265 s) was shorter than Curved Road(M=1.467 s); Main effect of With and Without-Secondary Task was marginally significant , $F(1,17) = 4.387$, $p= 0.052$,Without-Secondary Task (M=1.272 s) was shorter than With-Secondary Task(M=1.460 s).

3.2 Secondary Task Performance

Accuracy Rate and Reaction Time were analyzed by applying two-way repeated measures ANOVA in this part.

Accuracy Rate Main effect of Road Type was marginally significant, $F(1, 17) = 3.517$, $p= 0.078$.Accuracy Rate of Straight Road (M=0.875) was higher than Curved Road (M=0.851).

3.3 Physiological Indices

Heart rate (HR), heart rate variability (HRV), was analyzed by applying three-way repeated measures ANOVA in this part.

HR Main effect of secondary task was significant, $F(1, 18) = 10.971$, $p= 0.004 < 0.05$, heart rate with secondary task (M=80.568) was higher than without secondary task (M=78.470).

3.4 Subjective Mental Workload Rating

NASA-TLX includes six dimensions: Mental Demand, Physical Demand, Temporal Demand, Mental Demand, Own Performance, Effort, and Frustration Level. Total scores of different dimensions were analyzed using three-way repeated measures ANOVA.

Main effect of secondary task was significant, $F(1,18)=30.609$, $p= 0.000< 0.001$, the subjective mental workload rating scores with secondary task(M=11.700) were higher than without secondary task(M=8.709).The interaction between secondary task and road type was marginally significant, $F(1,18)=3.943$,$P= 0.063$, further simple effects tests revealed that only under the condition of Without-Secondary Task, there was significant difference between curved road and straight road(Curved Road > Straight Road).

The overall statistical significant results are summarized in Table 1.

Table1 Summary of statistically significant results

Measure	Effect	*Df*	*F*	*P*	Multiple comparison
SD of Car-following distance	Road Type	1,18	4.794	0.042	Straight Road> Curved Road
Mean of Lateral Position	Road Type	1,18	48.870	0.000	Curved Road> Straight Road
SD of Lateral Position	Road Type	1,18	67.061	0.000	Curved Road> Straight Road
	Road Type × Secondary Task	1,18	4.523	0.048	With-Secondary Task: Curved Road> Straight Road Without-Secondary Task: Curved Road=Straight Road
Accuracy Rate of reaction to the critical events	Road Type	1,17	10.900	0.004	Straight Road >Curved Road
	Secondary Task	1,17	5.226	0.035	Without-Secondary Task> With-Secondary Task
Reaction Time of response to the critical events	Secondary Task	1,17	4.387	0.052	With-Secondary Task > Without-Secondary Task
	Road Type	1,17	12.318	0.003	Curved Road> Straight Road
Accuracy Rate of Secondary Task	Road Type	1,17	3.517	0.078	Straight Road > Curved Road
HR	Secondary Task	1,18	10.971	0.004	With-Secondary Task > Without-Secondary Task
Subjective Mental Workload Rating	Secondary Task	1,18	30.609	0.000	With-Secondary Task > Without-Secondary Task
	Secondary Task × Road Type	1,18	3.943	0.063	Without-Secondary Task: Curved Road> Straight Road With-Secondary Task: Curved Road=Straight Road

4 Discussions

4.1 Car-Following Performance

The results generally supported our predictions concerning the lateral car-following performance. Mean of lateral position of the curved road was larger than the straight road, and SD of lateral position was partially affected by presence or absence of secondary task: only with presence of secondary task, there was significant difference between the curved road and the straight road (Curved Road > Straight Road), Which indicated that it was harder to keep the lateral position to the leading car on curved roads than straight roads, and the secondary task affected the stability of lateral control.

As for the longitudinal car-following performance, the results partially supported our prediction: SD of car-following distance of the straight road was larger than the curved road, which indicated that drivers tried more often on the straight road than curved road to keep "close but safe" distance, because on the straight road, it was easier to deal with the lateral car following than the curved road. However, mean of car-following distance was not a sensitive index, which contradicted with our prediction. According to the results of other studies (e.g. Ranney, Harbluk, & Noy, 2005) we had predicted that drivers increase their headway to maintain safety when performing a secondary task, especially the novice drivers. But the results showed no consistent difference between presence and absence of secondary task; no difference between novice drivers and experienced drivers was found, either. Simulation might be the reason, in which "accidents" was not as unacceptable as the real situation, and also, simulator need to be improved both in the vehicle control and driving scenarios.

Reaction time and correct response rate to the critical event (the leading car's signal) were sensitive to manipulation of road type and secondary task, which testified the conclusion of Rumar (1990): the failure to detect relevant driving events is a primary cause of traffic crashes.

4.2 Secondary Task Performance, Physiological Indices and Subjective Mental Workload Rating

The results of secondary task performance showed that arithmetic task accuracy rate was sensitive to road type, which indicated that arithmetic task was appropriate to be secondary task.

HR and HRV have been suggested as measures of mental workload (Mulder, 1992; Nickerl & Nachreiner, 2003). A decrease in HRV was known to indicate an increase in the mental effort and an increase of HR could be used as indictor of an increase in drivers' workload. The results only supported that HR was sensitive to secondary task. In addition, an interesting finding was that BR and BRV were sensitive to driving experience, which needs to be further testified considering the two indices were vulnerable.

As for the results of subjective mental workload rating, NASA-TLX was supported to be an effective tool; it was sensitive to secondary task and partially sensitive to road type (only without secondary task).

5 Conclusions

In Sum, mental workload could be an effective index of drivers' status. The measurement of driver's mental workload need develop a combined approach. Specifically, in this study, the combination of responses to the critical event, HR and subjective mental workload rating was an effective approach. Actual or potential of this research include developing driver status monitoring or warning system and developing an effective technique to evaluate driver distraction.

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