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A Study of a Driver Model Using Unconscious Driving Behaviors

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Abstract

The automation of automobiles will change driver behavior, as the unconscious region stressed by the conscious region. Driving operation is considered to be done unconsciously, as human biological signals start 0.3 seconds before a decision is made. It is thought that driving operation changes when the unconscious region is pressured. In this paper, we set mental calculations as a dual task technique of a non-driving task for drivers, and verified the changing of driver operations by this load pressure on a driver's consciousness region.

Keywords: human engineering, driver model, mental workload, unconsciousness, dual task technique ;

1. Preface

In recent years, vehicle operations have become increasingly automated. The change from MT cars to AT cars can be cited as a typical example of automation. With the shift from MT cars to AT cars, though the number of accidents has reduced and driving has become safer, it has been observed that there is an increasing proportion of accidents caused by human operations such as while turning and rear-end and head-on collisions, as shown in Figure 1[1]. Also, comparison of the ratios of accidents by each human factor shows that more people are not ensuring safety or not paying attention while driving, etc. From this, it seems that with increased automation, drivers are losing consciousness of driving operations. The horizontal axis in Figure 1 is calculated as shown in Formula (1).

$$\text{Accident ratio of AT or MT cars} = \frac{\text{No. of accidents of AT or MT cars}}{\text{Number of AT or MT cars}} \quad (1)$$

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In this research, the assumption is that changes are taking place because of the load tasks in addition to driving operations, as divers are not ensuring safety or not paying attention while driving. Therefore, it is necessary to verify what the effect will be on driving operations by loading the driver with tasks.

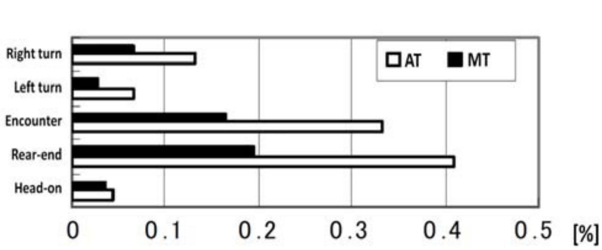

Fig. 1 Accident ratio comparison of accident types [1]

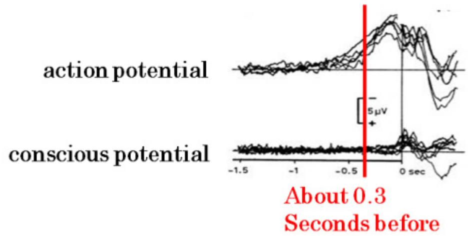

Fig. 2 Readiness potential [2]

When verifying driver behavior, the focus was on brain activity during driving operations. Looking at the brain activity, we found that the driving operations were reflex actions, and that the driver was not making conscious decisions. From this, we can establish the hypothesis that driving operations determine the unconscious and reflex actions after the situation is recognized.

Libet[2] proved this in 1983. In his research, there is an experiment in which the reactions from the subjects are sought in an arbitrary timing, and the brain activity related to that is observed. At that time, he measured the starting of the electrical signals known as readiness potential in the conscious potential that determines conscious actions, and the action potential that unconsciously tries to move the muscles. Figure 2 shows the starting of the two readiness potentials (conscious potential and action potential). From this, it is understood that, since the action potential occurs approximately 0.3 seconds before the conscious determining potential, the actions are unconscious and reflexive. And goals operations can be said to operate unconsciously[3].

From this, we consider a reflexive action model of drivers in which the unconsciousness state is taken into account. The current behavior model is comprised of the 3 factors of "Recognition, Judgment, and Operation"[4]. In occurrence of the readiness potential in the brain activity, the action potential occurs approximately 0.3 seconds before the conscious determining potential as mentioned in the previous paragraph. Accordingly, in this research, it is assumed that the actions are performed by reflexive operations comprising of the 2 factors of "Recognition (Judgment) and Operation". Thus it is thought that, when the driving operations are performed reflexively, the driver's conduct will be affected by his physical condition and changes within the car's environment.

2. Driver Model

In this research, the area used for driving operations is considered the unconscious area, and the area used for the processing of the sub-tasks as the conscious area, as shown in Figure 3, as habitual actions are carried out unconsciously without repeating conscious decisions. The assumption is that an increase in the conscious area will lead to the unconscious area being stressed, and cause increased frustration. Therefore, in the driving operations that are performed reflexively, it is thought that the driver's conduct will be affected by his physical condition and changes in environment in the car.

From this, assuming that the score of the activity area of the driver's brain is fixed, and that it is comprised of the scores of the conscious area and unconscious area, Formula (2) is established.

$$\sum_i f(\alpha_i \cdot a_i) + \sum_j f(\beta_j \cdot I_j) = P_k \quad (2)$$

In formula (2), $\sum_i f(\alpha_i \cdot a_i)$, represents the score of the unconscious area, $\sum_j f(\beta_j \cdot I_j)$ represents the score of the conscious area, and P_k represents the activity area of the brain when the driver is in k state. In this research, driving operations that are performed unconsciously are defined as the unconscious area, and other actions and thoughts that are performed consciously are defined as the conscious area. There are two factors, unconscious area in a_i and conscious area in I_j. α_i and β_j are considered as the variables after taking into consideration the individual's differences in each factor.

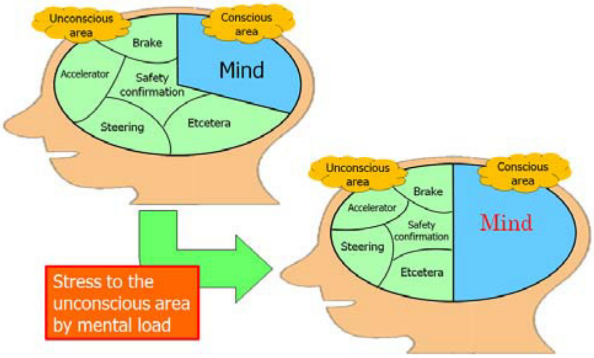

Fig.3 Assumption of stress to the unconscious area by mental load

3. Experiment Summary

3.1. Experiment Procedure

This experiment uses a 6-axis vibrating driving simulator (hereinafter "DS"). Before conducting the experiment, the purpose of the experiment was properly explained both in writing and verbally to the subjects participating in the experiment. Subjects also signed the consent form which indicated that they are voluntarily participating in the experiment. Then, this experiment was conducted after obtaining the approval from the Research Ethics Review Committee of the Shibaura Institute of Technology. The subjects of the experiment were comprised of 10 students (male and female) from the Institute and who held an ordinary motor vehicle license. As the course for the experiment, a highway with two lanes on one side was used. Once the subjects were adequately used to this driving, the sub-tasks were added and then the changes in the driver's conduct were measured. There are differences in the load ratio depending on the type of task, and in order to view these differences, the three patterns of no sub-tasks, mental calculation problems, and listening problems were measured twice each, for a total six times. In the experiment, an increase in the conscious area that happens when the driver gets used to driving is taken into consideration, and for the three types of situations, they were given weights such that listening problem > mental calculation problem > no load, and the driving test was conducted starting from the light weight.

In this course, two locations were deliberately prepared where the drivers had to sense and deal with the danger. Then the time to collision was measured.

The situations that the drivers dealt with are as follows.

A) There is an object fallen in front of the vehicle, and the lane is to be changed (Figure 4)

B) A construction vehicle has stopped, so the driver must merge into the right lane (Figure 5)

How the drivers reacted to avoid the danger in both the above mentioned situations was recorded, and the load on the drivers was verified.

Fig.4 Course scene A

Fig.5 Course scene B

3.2. Task Issue

Main task

- Subject is to follow the vehicle driving ahead at approximately 100 [km/h]

Sub-tasks

- "Mental calculation" in which the subject has to listen to 2 digit (between 10 and 99) addition problems which are given at approximately 6 seconds intervals, and give the answers orally
- "Listening problem" in which the subjects have to drive while listening to the radio, and after the driving ends, their understanding of what they listened to is checked

Keeping the main task fixed, the loads on the driver due to the sub-tasks are measured.

3.3. Experiment Results

In order to measure the driving load on the driver due to presence or absence of sub-tasks, the time to collision (hereinafter "TTC") when the participant started decelerating to avoid a collision with a vehicle stopped 100 [m] ahead, is shown in Figures 6 and 7. Figure 6, TTC 0[s] means that the crisis could not be avoided in time, and the driver collides with the vehicle ahead. TTC is calculated as shown in Formula (3).

$$\mathrm{TTC} = \frac{\text{Distance between stationary vehicle and own car} - 100[m]}{\text{Speed of own car}} \quad (3)$$

From Figure 6, we found that when anticipating the danger, the reaction of subjects 1, 2, 4, 5, 7, 8 and 10 tends to become slower in the sequence of normal time > listening problem > mental calculation problem. However, for subjects 3, 6, and 9, the reaction is slower during normal times compared to that during the listening problem. The experiment was conducted keeping sufficient intervals, but the pattern of the course used was the same, so the results showed that the subjects had developed familiarity with the course. The issue in the future will be that the experiment will have to be conducted in such a manner that the subjects do not develop any familiarity. This is to be done by changing the location where the crisis is to be avoided etc. In Figure 7, which shows the second location, we did not observe that the reactions of subjects 1, 5, 6, 7, 8, 9 and 10 tend to become slower in the sequence of normal times > listening problem > mental calculation problem, so an issue will be reverification in an unfamiliar environment. However, in scene A, where the effect of familiarity is less, when we look at the reaction for each load task, the TTC changes, and thus the conscious area expands because of the load task, and because the unconscious area gets stressed, the reaction gets delayed.

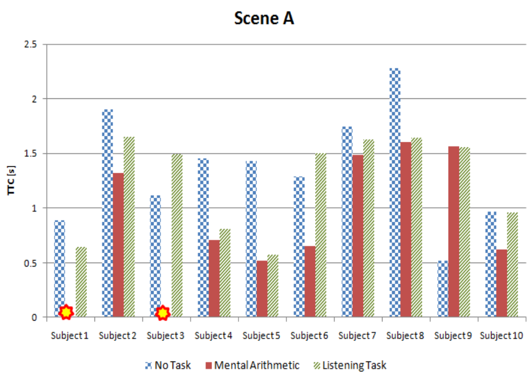

Fig.6 Time to collision in scene A

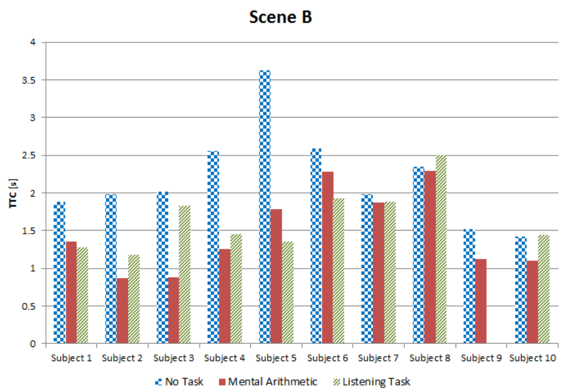

Fig.7 Time to collision in scene B

4. Driving Evaluation Using Proposed Method

4.1. VACP

VACP is a method in which the factors necessary for driving operations are subdivided and evaluated. First, tasks such as lane change which are performed dynamically by arbitrary judgment of the driver are known as driving tasks. A driving task is comprised of operations such as speed control, keeping in the lane, etc. These operations are classified one-by-one as sub-tasks as seen in Table 1. As shown in Table 2, the sub-tasks are divided into visual (V), auditory (A), cognitive (C) and psychomotor (P). The sub-tasks are then numerically represented between 1.0 and 7.0 depending on the quantity of cognitive resources consumed, as shown in Table 3. The total of these numbers is applied to the sub-task, and then the score is obtained. In this method, the total of the scored sub-tasks corresponding to each running environment is determined as the work load score.

Here, using the research on the driver work load estimation method by VACP[5] as reference, the VACP value in each situation of simple addition problems is set and compared with the actual driving experiment.

Table.1 Examples of driving tasks and subtasks

Task name	Subrasks contained in the task
Go straight	Adjust the speed / Keep the lane / Check the front / Check the side / Check the rear
Carve	Adjust the speed / Keep the lane / Check the front / Scan the side / Check the rear
Tracking straight	Adjust the speed / Track the object / Keep the lane / Scan the front / Check the side / Check the rear
Tracking carve	Adjust the speed / Track the object / Keep the lane / Scan the front / Scan the side / Check the rear
Pull into traffic	Adjust the speed / Keep the lane / Scan the front / Scan the side / Scan the rear
Overtake	Lane change / Scan the front / Scan the side / Scan the rear
Suddenly brake forward car	Adjust the speed / Sudden braking / Keep the lane / Lane change / Scan the front / Scan the side / Check the rear

Table.2 Scales of driver tasks for VACP

	Visual	Auditory	Cognitive	Psychomotor	Total
Adjust the speed	0.0	0.0	1.0	2.6	3.6
Sudden braking	5.0	0.0	7.0	4.6	16.6
Track the object	4.0	0.0	3.7	2.6	10.3
Keep the lane	0.0	0.0	1.0	2.6	3.6
Lane change	0.0	0.0	4.6	2.6	7.2
Check the front	4.0	0.0	1.0	0.0	5.0
Check the side	4.0	0.0	1.0	0.0	5.0
Check the rear	4.0	0.0	1.0	0.0	5.0
Scan the front	7.0	0.0	3.7	0.0	10.7
Scan the side	7.0	0.0	3.7	0.0	10.7
Scan the rear	7.0	0.0	3.7	0.0	10.7

Table.3 VACP scales

Visual

Scale Value	Verbal Descriptor
1.0	Visually register, detect occurrence
3.7	Visually discriminate
4.0	Visually inspect / check
5.0	Visually locate / align
5.4	Visually track / follow
5.9	Visually read (symbol)
7.0	Visually scan / search / monitor

Auditory

Scale Value	Verbal Descriptor
1.0	Detect / register sound
2.0	Orient to sound (general)
4.2	Orient to sound (selective)
4.3	Verify auditory feedback
4.9	Interpret semantic content (speech)
6.6	Discriminate sound characteristics
7.0	Interpret sound patterns

Cognitive

Scale Value	Verbal Descriptor
1.0	Automatic, simple association
1.2	Alternative selection
3.7	Sign / signal recognition
4.6	Evaluation / Judgment (Consider Signal Aspect)
5.3	Encoding / decoding, recall
6.8	Evaluation / Judgment (Consider Several Aspect)
7.0	Estimation, Calculation, Conversion

Psychomotor

Scale Value	Verbal Descriptor
1.0	Speech
2.2	Discrete Actuation (Button, Toggle, Trigger)
2.6	Continuous Adjustive
4.6	Manipulative
5.8	Discrete Adjustive
6.5	Symbolic Production (Writing)
7.0	Serial Discrete Manipulation (Keyboard Entries)

4.2. NASA-TLX

NASA-TLX is an evaluation method comprising of the 6 subjective evaluation scales of mental demand, physical demand, temporal demand, overall performance, effort, and frustration[6]. After the driving experiment ended, the subjects filled in a questionnaire related to the overall load for the 6 subjective evaluations and their standards, as shown in Table 3. Then the work load score was evaluated. In this experiment, an evaluation method known as the CSTLX method is used.

Table.4 NASA-TLX scales[6]

Scale name (end point)	Explanation
Mental Demand	How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex?
Physical Demand	How much physical activity was required? Was the task easy or demanding, slack or strenuous?
Temporal Demand	How much time pressure did you feel due to the pace at which the tasks or task elements occurred? Was the pace slow or rapid?
Overall Performance	How successful were you in performing the task? How satisfied were you with your performance?
Effort	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration	How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?
Overall load	When the various burden factors, load factors, and portions of the problem details are integrated, to what extent is the overall work load felt?

4.3. Correlation by VACP and NASA-TLX

In order to verify the correlation by VACP and NASA-TLX, the driving environment mentioned in “3.1 Experiment Procedure” is used. Using the VACP from the environment inside the car and the driving environment, the work load score is evaluated. Figure 3 shows the correlation with NASA-TLX, which is based on the subjective evaluation questionnaire the subjects answered after driving. In VACP, we found that there is a high correlation when driving during normal times with no load task. However, when a load task is added, it is difficult to evaluate using VACP because of the effect of the load task. How the conscious area is used for load task and the frustration caused by the suppression of the unconscious area will differ for each driver, and it is thought that these differences etc. have an effect. Therefore, the suppression of the unconscious area in the driver’s brain because of the load must be taken into consideration. Also, a driver model wherein the effect of individual differences is taken into consideration must be proposed.

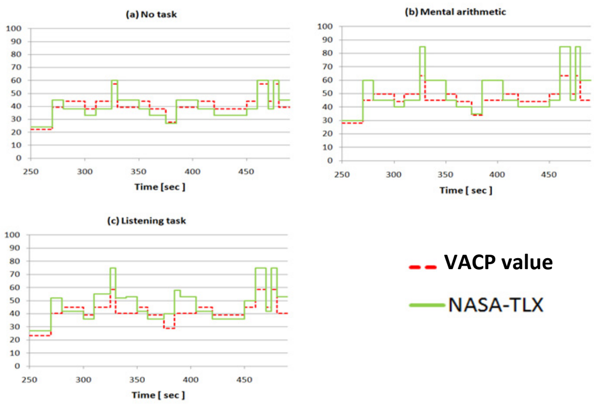

Fig.8 Comparison of the estimated VACP and NASA-TLX

4.4. Driver model in which work load score is considered

From the results of the experiment, we found that there are individual differences in the effects when a load task is added. From Figure 8, we also found that it is difficult to maintain the correlation if the work load score is evaluated using VCAP when adding load tasks. From this, we found that when the conscious area is small, there is a high correlation, but when the conscious area is big, there is a low correlative relationship. Therefore, the correlation with NASA-TLX when adding a load task is verified by applying VACP to the driver model in which the conscious area and unconscious area proposed in this research are taken into consideration. To estimate the state of the driver when a load task is added, based on the VCAP score, each factor variable α_i and β_j that matches with the driver is assigned. In the current experiment, the physical effect of the given load task is A (auditory). However, from the questionnaire on the driving operations when avoiding a crisis, which was answered after the driving experiment, we found that more than the physical effect, the mental effects from both the load task and driving task are larger. Therefore, in this research, the focus is on P (psychomotor) which indicates the psychological resources. With this, it is possible to estimate the work load score in which the individual differences are taken into consideration by assuming Visual, Auditory, and Cognitive as the unconscious area, and Psychomotor as the conscious area.

Thus, if Formula (2) is applied, it would be possible to estimate the work load score when a load task is added by assigning variables α_i and β_j to unconscious area $\boldsymbol{a_i}$ \and conscious area I_i. Figure 7 represents the VACP scores in which P (psychomotor) is henceforth taken into consideration. When compared with the conventional method as shown in Figure 9, we found that there are differences in the reactions when avoiding a crisis and during normal times. Also, since a numeric value that is comparatively close to the work load score felt by the subjects could be observed, it is assumed that a highly accurate estimation can be made by verifying the changes in the driving environment and the overall reaction.

Tab.5 Scales of driver tasks for VACP

	Visual		Auditory		Cognitive		Psychomotor	
Adjust the speed	α_{V1}	0.0	α_{A1}	0.0	α_{C1}	1.0	β_{P1}	2.6
Sudden braking	α_{V2}	5.0	α_{A2}	0.0	α_{C2}	7.0	β_{P2}	4.6
Track the object	α_{V3}	4.0	α_{A3}	0.0	α_{C3}	3.7	β_{P3}	2.6
Keep the lane	α_{V4}	0.0	α_{A4}	0.0	α_{C4}	1.0	β_{P4}	2.6
Lane change	α_{V5}	0.0	α_{A5}	0.0	α_{C5}	4.6	β_{P5}	2.6
Check the front	α_{V6}	4.0	α_{A6}	0.0	α_{C6}	1.0	β_{P6}	0.0
Check the side	α_{V7}	4.0	α_{A7}	0.0	α_{C7}	1.0	β_{P7}	0.0
Check the rear	α_{V8}	4.0	α_{A8}	0.0	α_{C8}	1.0	β_{P8}	0.0
Scan the front	α_{V9}	7.0	α_{A9}	0.0	α_{C9}	3.7	β_{P9}	0.0
Scan the side	α_{V10}	7.0	α_{A10}	0.0	α_{C10}	3.7	β_{P10}	0.0
Scan the rear	α_{V11}	7.0	α_{A11}	0.0	α_{C11}	3.7	β_{P11}	0.0

Unconscious area (Visual, Auditory, Cognitive) **Conscious area** (Psychomotor)

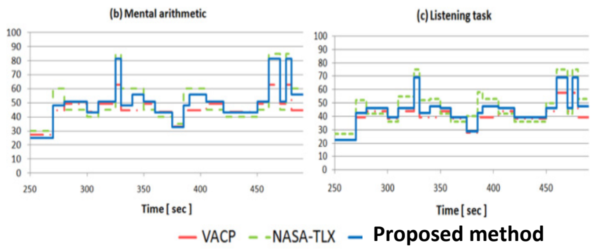

Fig.9 Comparison of three methods

5. Conclusions

In this research, the driving experiment was conducted after assigning load tasks to the drivers, and then the effects of those load tasks on the drivers were verified. The results from the driving experiment are as follows:

1. We found that when the load tasks are added, the proportion of conscious area increases, and the driving operation carried out by the unconscious area become slower. Also, there are individual differences in the effect on the unconscious area because of the load task, and the effects due to individual differences must be taken into consideration.
2. By applying this proposed method to VACP, it was confirmed that when a load task is assigned, the effect of the stress that the drivers felt when avoiding a crisis is more largely mental (P, psychomotor) than physical (A, auditory).
3. The results of the scores evaluated of the model comprised of the two factors of recognition (judgment) and operation show that there is a correlation. From the current experiment, we found that when load tasks are added, the psychological effect is greater than the physical effect. Therefore, a future issues is that the following must be verified.
4. This experiment was conducted with identical scores, so the results indicated familiarity. Hence, reverification must be done by conducting the experiment in which no familiarity arises. This is to be done by changing the location where crisis is to be avoided, etc.
5. Verification must be conducted to check whether there are changes in the psychological effects when the drivers are used to the load tasks.
6. Whether there are any changes in the psychological effect or physical effect due to tracking task or inattentive task which is a physical load or task which has different kinds of load, is to be double checked.

The numeric values of variables α_i and β_j must be determined by double checking the measurement method and environment changes.

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