Development of Thumb-Operated Dial-Type Integrated Switch for Automobile and its Effectiveness

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Abstract— **A thumb-operated dial-type integrated switch for automobile use was developed, and the task completion time for this type of integrated switch was compared with that for a traditional integrated switch. The rotation torque of an encoder and the rotation diameter were selected as experimental parameters. An attempt was made to identify the optimal and recommended condition of rotation torque and diameter. It was demonstrated that the thumb-operated dial-type integrated switch lead to faster task completion time as compared with the traditional integrated switch. As for the thumb-operated dial-type integrated switch, the following combination of the rotation torque and the rotation diameter were not proper: diameter of 20 mm for the rotation torque of 12.9mN・m and 9.2mN・m, and diameters of 20mm and 40mm for the rotation torque of 8.6 mN・m. It was also suggested that the optimal condition cannot be identified using the condition of the rotation force only, and that the optimal condition must be determined taking into account the combination of the rotation torque and the rotation diameter.**

1. Introduction

With the growth of intelligent transportation systems (ITS), such as car navigation systems or hands-free cellular phones, driving is becoming more and more complex[1]. As much of the information provided contains texts and images, drivers are apt to become distracted and inattentive. Driving a car places a characteristically heavy workload on visual perception, cognitive information processing, and manual responses[2]. Drivers often simultaneously perform two or more tasks; for example, they adjust the volume of a radio or CD player and control the air conditioner to adjust the temperature while driving. Such sharing of attention may lead to dangerous situations. Previous research in the area of displays and controls for secondary devices in automobiles is notable for the lack of reported work on compatibility. Most research discusses design of the display or the control, but not the way in which they are to operate together, which includes effects of compatibility.

Lambel, Kauranen, Laakso, and Summala and Lambel, Laakso, and Summala discussed the relationship between display location and performance in car driving situations[3],[4]. Lambel, Laakso, and Summala reported that the driver's ability to detect the approach of a decelerating car ahead was affected by the display location[4]. Waller and Green[5] examined switch type and its location, and pointed out a lack of consensus as to where the control should be located. Proper control (switch) location must be one of the important factors to assure fast responses of drivers.

Makiguchi et al. [6] demonstrated that steering wheel mounted controls were more effective than controls on the instrumental panel. However, they did not examine the effectiveness of steering wheel-mounted switches by taking the display location factor into account. Although Wierwille[7] stated that in-car controls and displays should be designed by taking visual and manual demands into account, he did not give guidelines for where the displays and controls should be located. Murata and Moriwaka[8] investigated how the number and arrangement of steering wheel mounted switches interactively affected performance. They found that the cross-type arrangement with three switches provided best performance and highest psychological rating.

These studies did not take the memory factors into account to the design of display with layered structures. The display design also should consider the findings on eye movement characteristics that horizontal eye movement is faster and easier than vertical eye movement. Although Murata and Moriwaka[8] investigated how the control should be designed without taking the display factors into account, the interaction between display and control factors must be investigated in order to obtain a more proper design guideline.

A variety of knob, lever, press switch, rotary switch, and toggle switch is arranged in the automobile cockpit module [9]. These controls are mainly used to operate an AM/FM radio, or adjust the temperature in the vehicle. The operation of such controls induces operational workload [7], [10]. The usability of controls is affected by

installation location, frequency of use, ease of differentiation, etc. Moreover, it has been suggested that the controls should be placed taking the display system into account [11].

Dukic et al.[12], [13] showed that the switch (control) location close to the gear stick which has highest eccentricity produced a shorter time off road (the time period when drivers look aside). Moreover, Dukic et al. [13] showed that older adults spent longer visual time off road when pushing the switches and had larger steering wheel deviations. Although Dukic [12], [13] did not use an integrated switch, they predicted, on the basis of their results, that the integrated switch should be installed on the drivers' side from the viewpoint of decreasing time off road.

With the progress of by wire technology in automobile utilization, it is possible to install controls to a variety of sites and carry out a lot of secondary tasks using these controls. Although the integrated switches are practically used in IDrive of BMW or Honda Odessay, the effectiveness or the design guideline has not been explored thoroughly and satisfactory. Although McCormick et al. [9] suggested the importance of proper design of controls, there seem to be few detailed studies that specified how to design and utilize such controls.

Bradley [14] discussed optimal knob diameter, and showed that the relationship between turning time and knob diameter (U-shaped curve) becomes essentially flat in the region from 3 and 1/4 inch to 1 inch when friction resistance was reduced to a moderate level. When friction resistance was very low, the U-shaped curve would flat out, and turning time became less affected by knob diameter. However, how rotation torque and diameter affected the turning time had not been examined. In other words, it had not been stated how rotation torque and diameter should be designed to produce a usable control. Moreover, in Bradley [14], the task situation where something is controlled by a knob has not been assumed. Although Carter [15] examined an ergonomic design of knobs used under water, he referred to only diameter design. Øvergård et al.[16] discussed how different knob sizes and torques affected operator performance, and indicated that ergonomically recommended ranges of knob sizes might differently affect operator performance. However, it was not clarified how the combination of diameter and rotation torque affected the operator performance. The results above [14]-[16] cannot be directly applied to the design of automotive integrated switches.

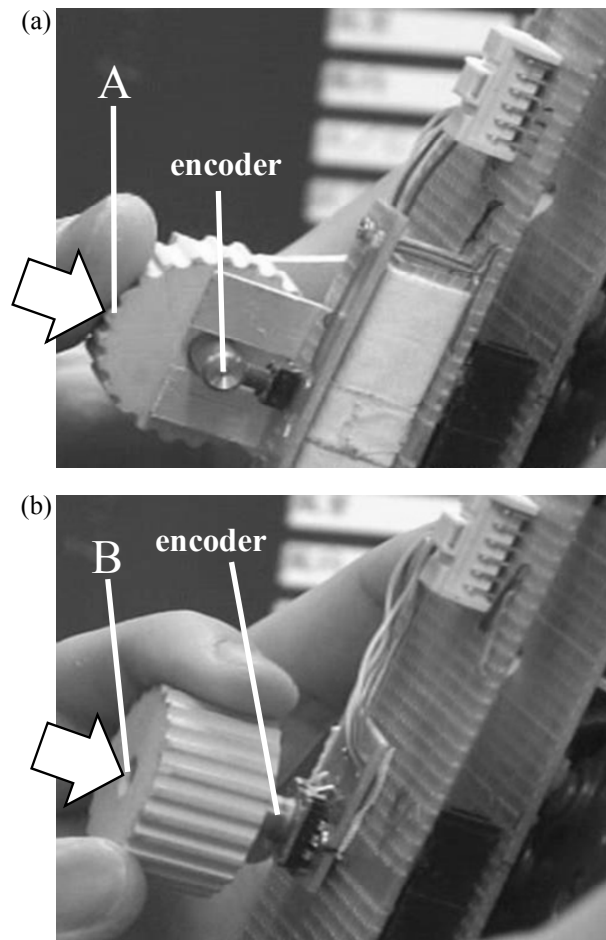The integrated switches have an advantage over

Photo 1 (a) Thumb-operated dial-type integrated switch, (b) Traditional dial-type integrated switch.

traditional ones that many functions are integrated into one switch, therefore saving spaces for installing a lot of switches. Although the spread of integrated switches are expected further with the progress of by wire technology, the design guideline of traditional integrated switches has not been established. Moreover, the potential candidates which have more advantages over the traditional steering switches has not been proposed from the viewpoint of ergonomics. Therefore, a new type of integrated switch which has a definite advantage over the traditional one has been developed and proposed in this study.

In this study, a thumb-operated dial-type integrated switch has been developed with rotation torque and diameter as experimental parameters, and the validity of the developed integrated switch has been verified. The task completion time (operation time) of the thumb-operated dial-type integrated switch was compared with that of the traditional integrated switch.
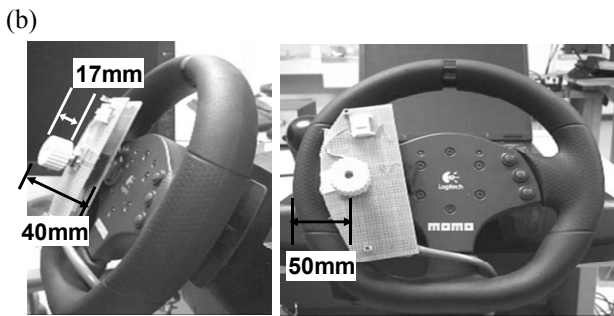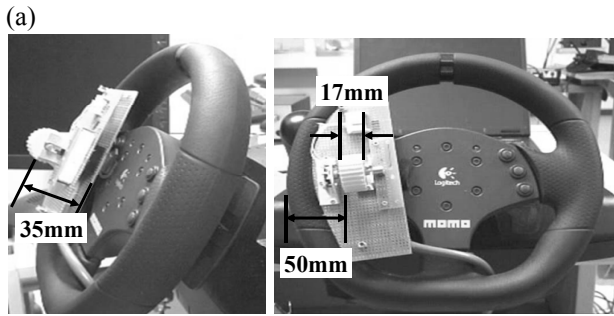
(a)

17mm

35mm

50mm

(b)

17mm

40mm

50mm

Photo2 (a) Installation of thumb-operated dial-type integrated switch, (b) Installation of traditional dial-type integrated switch.

Fig.1 Display for menu selection task.

Integrated switch

70cm

70°

Display for menu selection task

70cm

40cm

Photo3 Outline of experimental setup.

2. Thumb-Operated Dial-Type Integrated Switch

Three types of 11GS encoders (Panasonic Electronics, EVER004Z9017:8.6Nm・m, 9.2Nm・m, 12.9Nm・m) were used to produce a integrated switch. It takes 24 clicks for these encoder to cycle around (One click moves the encoder by 15 degrees). The switches as shown in Photo.1 were made with these encoders. The thumb-operated dial-type integrated switch (Photo.1(a)) can be operated with only a thumb. The rotation of dial makes users select a menu as shown in Fig.1, and the press of key A in Photo.1 (a) terminates the selection. In the traditional integrated switch (b), the rotation of dial is carried out by pinching the dial with a thumb and an index finger, which enables users to select a menu item. The determination of menu selection is conducted by pressing B in Phot.1 (b). This type of integrated switch is practically used in iDrive of BMW or Odessay of Honda. The installation of these switches is shown in Photo.2.

The diameter conditions of 20, 25, 30, and 40mm, and the rotation torque conditions of 8.6, 9.2, and 12.9 Nm・m were selected in this experiment.

The rationale for developing a thumb-operated dial-type integrated switch is mentioned below. The traditional integrated switch requires us to take time to move a thumb to B in Photo.1(b). On the other hand, the thumb-operated dial-type integrated switch does not need such time. Therefore, it might be reasonable to assume
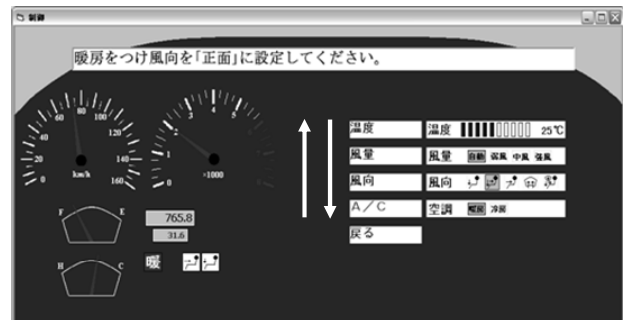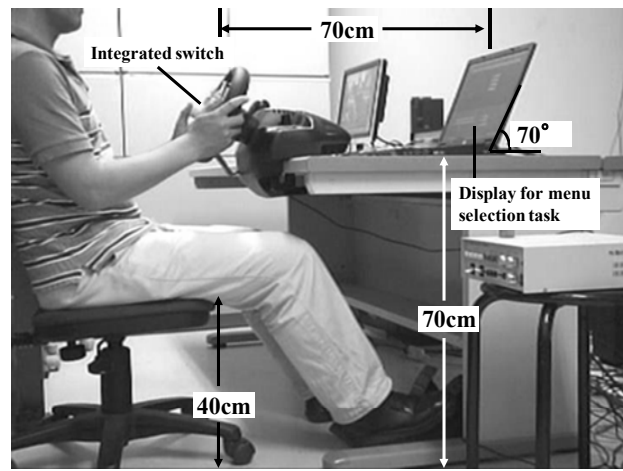
that the thumb-operated dial-type integrated switch would lead to shorter operation time, if the conditions of rotation diameter and torque are selected properly.

The effectiveness of the developed thumb-operated dial-type integrated switch is verified, and the optimum condition of rotation torque and diameter is recommended.

3. Method
3.1 Participants

Twenty participants from 21 to 23 years old took part in the experiment. All had held a driver's license. Stature of participants ranged from 160 to 180 cm. The visual acuity of the participants in both young and older groups was matched and more than 20/20. They had no orthopedic or neurological diseases.

3.2. Apparatus

Using the developed integrated switches (See Photo.1 and Photo.2), the experiment was carried out under the sitting condition. A video timer (FOR A, VTG-33) was
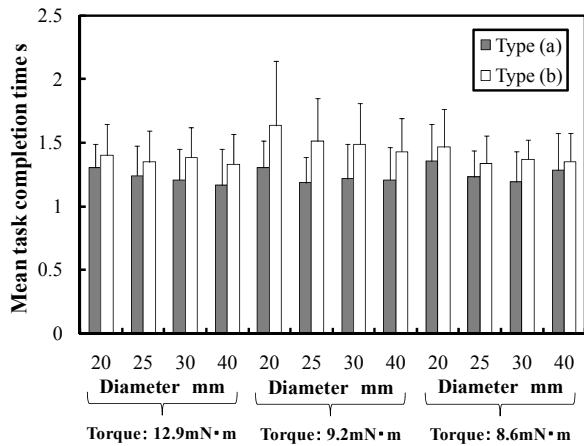
Fig.2 Mean task completion time as a function of diameter, torque, and switch type.
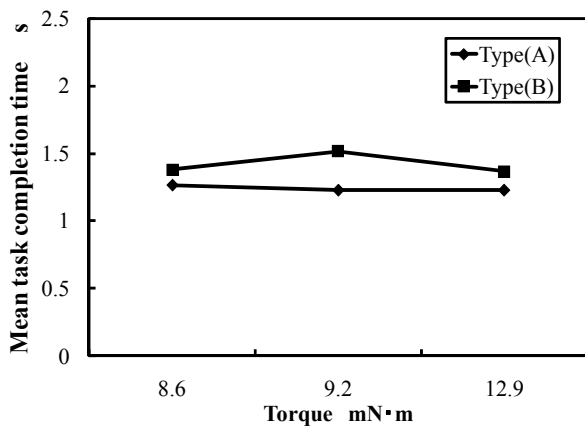

Fig.4 Mean completion time for reaction time1, reaction time2, and total reaction time (task completion time) as a function of switch type.

Fig.3 Rotation torque by switch type interaction for task completion time.

Rotation force (N)	0.43	0.46	0.57	0.61	0.64	0.69	0.74	0.86	0.86	0.92	1.03	1.29
Diameter (mm)	40	40	30	30	40	25	25	30	20	20	25	20
Torque (mN・m)	8.6	9.2	8.6	9.2	12.9	8.6	9.2	12.9	8.6	9.2	12.9	12.9

Fig.5 Mean task completion time as a function of rotation force.

used in order to measure the task completion time with the accuracy of 1/100 s. A steering wheel (Logitech, MOMO Racing Force Feedback Wheel) was used.

3.3 Task

The experimental task was to move the cursor of menu selection display in Fig.1 upward and downward or vice versa using an integrated switch (a) or (b). The cursor was moved by three clicks upward and downward, respectively. After moving the cursor three clicks upward and downward, the determination key (A and B in Photo.1 (a) and (b), respectively).

3.4 Design and procedure

For both types of integrated switch, the task above was repeated 20 times for each combination of rotation torque and diameter. In the 20 trials, ten trials were carried out with upward first and downward second. The other ten trials was vice versa. In other words, two types (upward first and downward second trial and downward
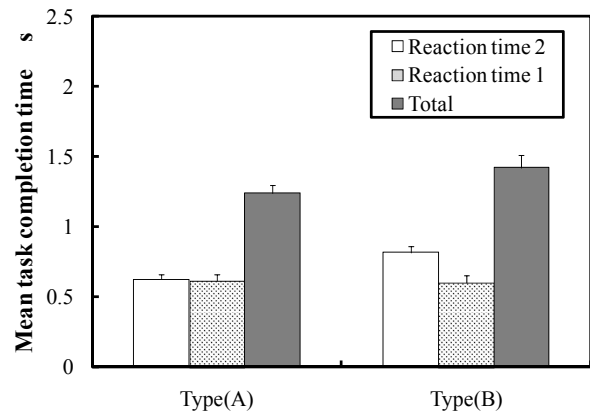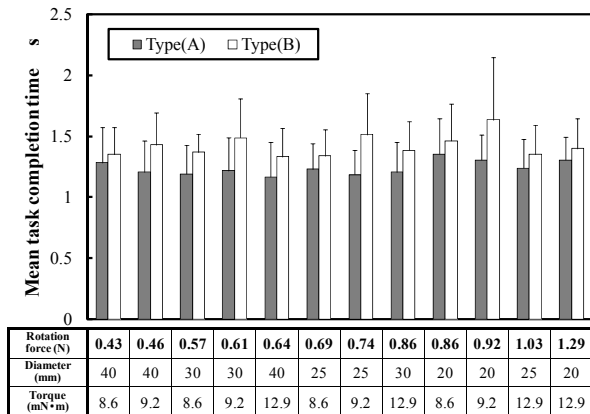
first and upward second trial) were included. The order of performance of the two types was randomized across the participants, and across the combinations of rotation torque and diameter. The order of performance of two types of switch was counterbalanced across the participants.

The error trials were excluded from the analysis of task completion time. The task completion time corresponded to the interval from the display of task to be conducted to the press of determination switch. The task completion time was divided into the following two components: reaction time1 (time interval from the display of task to be conducted to the completion of rotation) and reaction time2 (time interval from the completion of rotation until the press of determination switch). The outline of experimental situation is shown in Photo.3.

4. Result

For both thumb-operated dial-type integrated switch and traditional integrated switch, the percentage of error operations were less than 1% for all combinations of diameter and rotation torque.

In Fig.2, the mean task completion time is shown as a function of diameter, torque, and switch type. A three-way (diameter by torque by switch type) ANOVA carried out on the task completion time revealed main effects of switch type (F(1,19)=41.207, p<0.01), diameter (F(3,57)=9.088, p<0.01), and torque (F(2,38)=4.028, p<0.05). A torque by switch type interaction was statistically significant (F(2,38)=4.078, p<0.05). In Fig.3, the torque by switch type interaction is depicted.

The task completion time was divided into reaction time1 and reaction time2. In Fig.4, the reaction times 1 and 2 are depicted as a function of switch type. A two-way (torque by diameter) ANOVA carried out on the reaction time1 revealed only a main effect of diameter (F(3,57)=5.198, p<0.01). The difference of task completion time between two types of switches was found to be due to the reaction time2.

The rotation force can be calculated by dividing rotation torque by diameter. In Fig.5, the task completion time is shown as a function of rotation force. The force condition was divided into the following two categories: (A).force from 0.46 to 0.92 N (The conditions of diameter of 20 mm and torque of 8.6 Nm・m and, that of diameter of 20 mm and torque of 9.2 Nm・m are excluded), (B)conditions other than (A).The categories (A) and (B) included 8 and 4 conditions, respectively. As a result of a t-test, the task completion time of (A) was significantly shorter than that of (B) (t=14.152, p<0.01).

5. Discussion

From Fig.2, it is clear that a thumb-operated dial-type integrated switch requires less time than a traditional integrated switch. The reason must be, as shown in Fig.4, that a thumb-operated dial-type integrated switch needs less time to press a determination switch after rotating a dial that a traditional one.

In a thumb-operated dial-type integrated switch, rotating a dial by one click to the upward makes the selection of menu item move by one item to the upward (See Fig.1). In the traditional integrated switch, on the other hand, turning a dial clockwise make the selection of menu item move by one item to the downward. From the viewpoint of compatibility[17], a thumb-operated dial-type integrated is more compatible than a traditional

one. Although there were no significant differences of reaction time 1 between two types of integrated switches (See Fig.4), it might be possible that a thumb-operated dial-type integrated switch becomes faster than a traditional one in a more practical and real-world situations.

From Fig.2, the following conditions are desirable for a a thumb-operated dial-type integrated switch: 25, 30, and 40 mm of diameter for rotation torque of 12.9mN・m, 25, 30, and 40 mm of diameter for rotation torque of 9.2mN・m, 25and 30mm of diameter for rotation torque of 8.6mN・m. For the condition of 40mm of diameter and 8.6 mN・m, it was clarified that a quick operation was impossible because of larger diameter. As for the traditional integrated switch, the reaction time for rotation torque of 9.2 mN・m was longer than that of other conditions of rotation torque (This might be the cause of a significant rotation torque by switch type interaction). For the rotation torque of.9.2 mN・m, it is impossible to attain higher performance except for the condition of 40 mm of diameter. For the rotation torque of 12.9 Nm・m, the diameter had less effects on the reaction time, and the diameters of 25, 30, 40 mm would be recommended. For both types of switches, the diameter of 20 mm is not recommended.

As shown in Fig.5, except for the diameter of 20 mm, it seems that the desirable rotation force of the thumb-operated dial-type integrated switch ranges from 0.46 to 0.86 N. However, the following exceptions are observed. When the diameter and the rotation torque are 20mm and 8.6 mN・m, the rotation torque is equal to 0.86 N. However, as mentioned above, this condition is not proper, because the diameter equals 20 mm. Although the condition with the diameter of 25 mm and rotation torque of 12.9 mN・m leads to faster reaction, the corresponding rotation torque is out of this range (0.46–0.86 N). Therefore, it is difficult to make a unitary conclusion on the usability of an integrated switch using only rotation force. Therefore, taking both diameter and rotation torque into account and determining an optimal design condition of an integrated switch would be desirable.

The reason why the diameter of 20 mm is not proper for the design condition of an integrated switch would be discussed. The encoder used in this experiment need 24 clicks to cycle around. Therefore, one click rotates the encoder 15 degrees. The movements per one click of encoder for 20, 25, 30, and 40 mm are 7.85, 9.81, 11.78, and 15.70 mm, respectively. The longer reaction time of diameter of 20 mm might be due to the shorter movement per one click. In the range of this experiment,

Table1. Recommended design parameter for each switch type.

○ : recommended   × : not recommended

Switch type	Torque mN·m	Diameter mm			
Type (a) Thumb-operated	12.9	20 ×	25 ○	30 ○	40 ○
	9.2	20 ×	25 ○	30 ○	40 ○
	8.6	20 ×	25 ○	30 ○	40 ×
Type (b) Traditional	12.9	20 ×	25 ○	30 ○	40 ○
	9.2	20 ×	25 ×	30 ×	40 ×
	8.6	20 ×	25 ○	30 ○	40 ○

it is recommended that the movement per one click needs more than 9.81 mm.

Øvergård et al.[16] showed that high torque lead to longer operation time, and lower torque lead to frequent errors. The lower workload to fingers and a hand does not necessarily give us an optimal operation condition. In this study, the relationship between rotation torque and diameter was not referred to. As clarified in this study, the usability of integrated switch cannot be evaluated using a one-dimensional (unitary) measure. The integrated switch must be designed by taking the relationship between rotation torque and diameter into account.

As for the traditional integrated switch, the following combination of rotation torque and diameter are recommended:(12.9mN·m, 25mm), (12.9mN·m, 30mm), (12.9mN・m, 40mm), (8.6mN・m, 25mm), (8.6mN・m, 30mm), (8.6mN・m, 40mm). The optimal conditions for both thumb-operated dial-type integrated switch and traditional integrated switch are summarized in Table 1. Future research should verify the effectiveness of thumb-operated dial-type integrated switch in real-world situations. The effect of location of thumb-operated dial-type integrated switch should also be examined.

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