JESK
J Ergon Soc Korea 2017; 36(1): 9-21
http://dx.doi.org/10.5143/JESK.2017.36.1.9
http://jesk.or.kr eISSN:2093-8462

An Ergonomic Shape Design for Automotive Push-Return Switches

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Received : October 07 2016
Revised : November 28, 2016
Accepted : December 07, 2016

Objective: The objective of this study is to understand the effect of angle and curvature of push-return switches, which are external factors in the operation environment inside the cars, on the feel of operation and to propose optimum alternatives.

Background: Customers' needs for products are changing from functional and performance aspects to customer-led type where customers can reflect on their needs on the products. The operation inside cars is executed by HMI. The push-return switch is utilized as the most intuitive mode of HMI; therefore, this push-return switch, which is widely used, has to be developed by assessing the preference and satisfaction of the customer.

Method: The angle and curvatures, which are external factors that affect the feel of operation, are drawn through surveying the preceding research literatures. The stages to construct alternatives in experiments are as follows: (1) the tactile switch is replaced after dismantling the switch assembly to evaluate the internal characteristics proposed by preceding researches, (2) a drawing is prepared by using a design software, is printed using 3D printer, and then it is attached on the switch assembly, and (3) evaluation for satisfaction of operation is carried out by using a driving simulator.

Results: Both the angle and curvature that are external factors of switch significantly affect the feel of operation. However, interaction between the two factors is found insignificant. Therefore, an optimum alternative is proposed considering the experimental outcomes.

Conclusion: This study evaluates the satisfaction in operation that affects the feel of operation environment inside the cars. Based on the study results, a guideline for switch design in the center fascia is proposed.

Application: This study is expected to be used as basic data for designing automotive switches, as well as switches in the industries similar with the operation environments of cars.

Keywords: Feel of operation, Automotive switch, Curvature, Angle, Satisfaction

1. Introduction

Customers' needs for existing products have been limited to functional and performance aspects. However, as income level improves and socio-cultural development progresses, requirements by the users also expand to various scopes, and change quickly. As competition becomes tough, the performance and quality of the products are also improved and standardized. These aspects of performance and quality are no more competitive elements in product development (Lai et al., 2006). Consequently, product development process has been changed from manufacturer-led type in the past to user-lead type where customers participate in the product development so that their needs can be reflected right on the products (Foxall and Johnston, 1987). Under such product development scenario, correct understanding needs and preference of the customer become of utmost interest and become essential requirements for an enterprise to survive. Designers need to understand how customers recognize and understand products (Hsu et al., 2000; Krippendorff, 1989; Lin et al., 1996). The automotive industry is striving to improve the satisfaction of the customers by reflecting on customers' preference not only for exterior and interior parts of the cars but also for the human-machine interaction between drivers and cars, matching with the changes in the product development paradigm (White, 2001).

Cars secure their position as an essential item for modern men and more than mere transportation means. Drivers become aware not only of the functional aspect of driving but also cars' convenience of use and consequent satisfaction (Park et al., 2010; Jung, 1997). The operation of information inside the cars is executed by HMI. HMI refers to all the means and devices that can be operated by users by recognizing internal and external situations during driving or during idle time and by understanding the interaction between humans and machines (Yang and Kang, 2008; Jung and Lee, 2014). This HMI can be broadly categorized into touch screen, and knob and push buttons, which are physical switches (Kim et al., 2014).

Drivers need to have visual and physical capabilities while executing several motions such as the operation of steering wheel and pedal for the primary task of driving. The tasks of operating air-conditioning or infortainment inside the cars are external factors during driving and these are defined as secondary tasks (Lansdown et al., 2004; Young et al., 2007). Such secondary tasks need focus on the information not related with driving, thereby attention needed for driving becomes dispersed and is a major cause of car accident (No and Lee, 2015; Stutts et al., 2001). To minimize accident risk occurring due to dispersion in attention caused by the secondary task, the HMI of the cars should be designed in an intuitive way. Intuitive interface is defined as an interface that can be used easily and promptly (Naumann et al., 2007; Hurtienne and Blessing, 2007). In this viewpoint, the push button that minimizes the attentiveness of gaze has a clear force feedback, blind control, whereas action affordance for pressing action is the most widely used in HMI inside cars from the past until now in terms of safety, intuitive operation, and simplicity aspects compared with touchscreen, which has dispersion of attention as a potential risk due to high visual dependency (Burnett et al., 2004; Dennerlein et al., 2000; Arsenault and Ware, 2000; Byeon, 2008).

Factors that make a difference in the feel of operation of this push button are broadly categorized into internal factors and external factors. Internal factor refers to the change in operating force that is exhibited by operating switches, which becomes enlarged till a maximum value when a user presses the switch and is abruptly decreased after the maximum value. Due to such difference in the force, a user can recognize if the switch is operated. Operating force inside the switch is displayed as non-linear characteristic. At this moment, peak force which is a maximum pressing force, drop force which is the difference between maximum force and the force when switch touches contact, and stroke which is a depth of force when switch touches contact in the point of inflection affect the feel of operation. Such internal factors have relative weight in the order of stroke, peak force, and drop force (Kosaka et al., 1993; Watanabe and Kosaka, 1995; Takehana et al., 2009, Ban and Jung, 2014).

For the internal factors of switch, many researches were conducted in relation with force and stroke even till sensitivity aspect. The review of preceding researches that were conducted with the seven types of cars packages such as the peak forces of five different operating forces (i.e., 1.5N, 2.0N, 2.5N, 3.0N, and 5.0N, door trim, crash pad, center fascia, center console, overhead console, and steering wheel) revealed that both the operating force and package location affected the feel of operation. Users preferred the operating force at around 2.5~3.0N, which also showed difference by the operation mode. In case of tapping zone where switch was comfortably pressed, an operating force of 2.5N was the most preferred, while in a reaching zone where switch was pressed by stretching hands and a grasping zone where hands were wrapped, an operating force at 3.0N was the most preferred (Ban et al., 2013).

Further, when a stroke that was in operating depth was divided into 2.5mm, 5mm, and 7.5mm, their effects with subjective satisfaction were evaluated, and the satisfaction was significantly different between depths of button operations. When button operating depth was at 5mm, the highest subjective satisfaction was achieved compared with 2.5mm and 7mm (Park and Jung, 2014). Operating force was also related with the sensitivity of switch operation. In the preceding researches carried out for the structural assessment of switches and sensible quality during operation of the cars, 92.3% of depth was explained as stroke; 87.8% of feel of weight as peak force, stroke, and drop force; and 57.2% of moderation as drop force and stroke. Further, depth, weight, and moderation explained luxury and dynamics as 89.3% and 73.0%, respectively, while luxury and dynamics explained 95.6% of the whole sensory satisfaction.

The external factor of switches was referred to as shapes of the switches. As shapes of switches that affected the feel of operation, there were flat, concave, and convex-type switch surfaces, and angles of switches. Push button, which is widely being used in the industrial sites, gives a feeling of being well-matched to the finger when its surface is concave-shaped (Stanton, 1997). In the atomic energy field, a concave surface design is suitable for users (O'Hara et al., 2002). Further, convex-type switch can draw an affordance of pressing, and possesses a concept compatibility of increase or upwards; thus, it can be used widely in industrial sites. Therefore, the above concept was also implemented in the button of the steering wheel of manufacturers' finished cars, even in the task in which pressing action is a major task such as keyboard.

According to the surface architecture of the keyboard, there is a difference in preference, degree of fulfillment, and fatigue level (Ilg, 1987). Angle is also one important factor that affects the feel of operation of switch. The preceding researches about subjective satisfaction and operating force according to switch angles showed that both the subjective satisfaction and operating force were significantly affected. The button operating force was decreased till 20° and then increased from the angle of 30°, while subjective satisfaction was increased until the switch angle was at 20°, followed by a decrease at 30° (Park and Jung, 2014). In addition, in the preceding researches that drew relative importance among stroke, peak force, and drop force, which are internal factors of switches, surface shape, which is an external factor, and switch angle, external factors occupied 44.85% among 100% of the feel of operation (Choi et al., 2015). The results indicate that shape as an external factor affects largely the feel of operation as much as internal factors.

However, such external factors of switch have not been studied as much as the internal factors, especially in the area of operation environment inside the cars. Therefore, it becomes necessary to conduct a study that considers not only internal designing factors but also external factors in order to correctly understand the feel of operation for switch by the users. This study aims to investigate the effect of surface shape and angle of switch which are external factors under the operation environment inside the cars, and to propose optimum alternatives considering the interaction of the two factors.

2. Method

2.1 Definition of factors

2.1.1 Independent factors

In this study, curvature and angle of switch were selected as external factors that affected the feel of operation based on the preceding researches and consultation with experts of switch design. Curvature refers to a degree of flatness and roundness of switch surface. When size of switch is fixed, its curvature is decided by radius of curvature, which is a radius between two points from both ends and center of circle and is indicated as 1/R (Strey, 1994). Further, it can be explained by height of arc at the chord from the line that connects both end points. Angle is defined as a gradient of projection of switch from the wall (Figure 1).

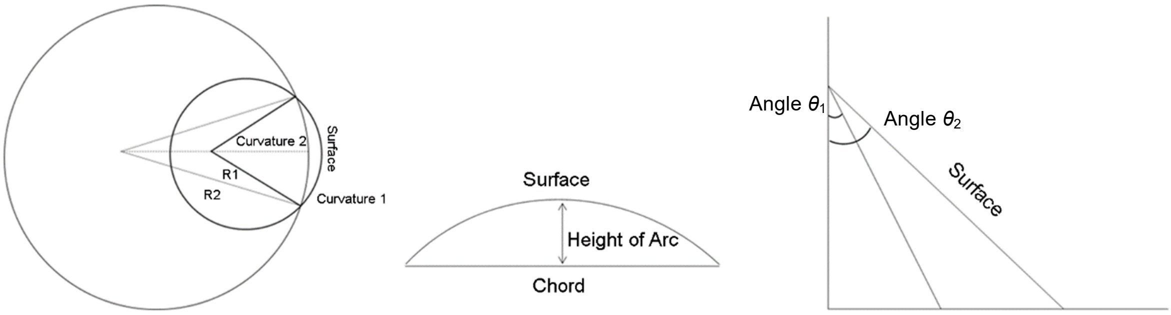

Figure 1. Curvature and angle

2.1.2 Dependent factors

Stimulus received through sensory systems has a hierarchical structure that composes complex sensibility from a simple sensibility to make an overall feel of satisfaction or dissatisfaction (Choe, 2013). Therefore, in this study, overall satisfaction of operation at the top was set as dependent factor, and seven-point Likert scale was used for analysis.

2.2 Plan for experiment

Since this study aims to investigate the difference in feel of operation for external factors of switch, internal factors like stroke, peak force, and drop force were controlled. By reviewing preceding research results that investigated the physical characteristics of commercial switches and those proposing the relative importance of parameters that affected the feel of operation, stroke was set at 0.65~1.15mm, peak force at 2.5~3.5N, and drop force at 1.00~1.75N as internal factors (Choi et al., 2015).

External factor angles were set at six levels of 0°, 5°, 10°, 15°, 20°, and 25°. Meanwhile, curvatures were set as a total of five radii of curvatures at 12.2mm and 22mm for convex-type switches, 12.2mm and 22mm for concave-type, and one level for flat one. Therefore, a total of 30 sets were drawn as shown in Table 1.

Table 1. Experimental alternatives

Stroke	Peak force	Drop force	Angle	Radius of curvature (Curvature, Height of Arc)
0.65~1.15	2.50~3.50	1.00~1.75	0	12.2 (0.082, 2.50)
			5	22.0 (0.045, 1.25)
			10	0.00 (0.000, 0.00)
			15	22.0 (0.045, -1.25)
			25	12.2 (0.082, -2.50)

To reflect the internal factors of switches, the switch assembly was dismantled, the existing tactile switch was removed, and then

30 switches from Alps Co., Ltd having physical characteristics proposed as above were fixed on the printed circuit board with the help of adhesive. Also, external factors were reflected in the experimental sets. First, a drawing, in which there were two types of factors, was reflected using Autodest 123D Design Software. Next, prepared drawing was printed using Edison Plus 3D Printer (Rokit Co., Ltd.). Lastly, external shape printed at last was attached on the switch assembly using an adhesive (Figure 2).

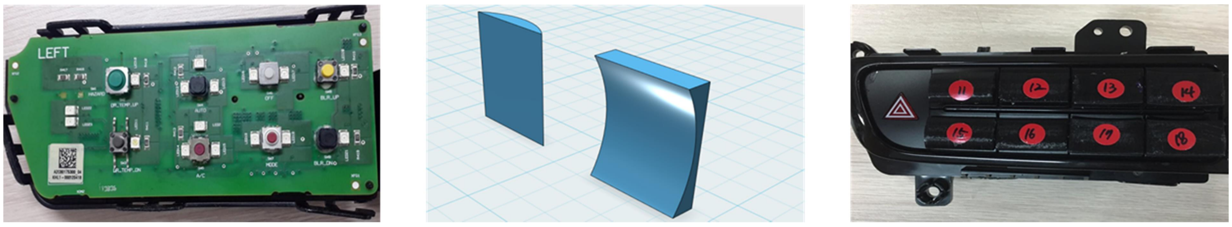

Figure 2. Printed circuit board, design software, and switch assembly

In the preceding researches which proposed the optimal range of emergency light switch in the center fascia, 18mm long x 15mm height was proposed as a size of button for 50% of users, while as size of button for 95% of users, 37mm long x 29mm height was proposed (Choi et al., 2010). Therefore, in this study, the size of switch was fixed at 22mm x 15mm, considering the research outcomes of preceding researches and commercial switches. Similar color as actual cars and plastic materials was used for the experiment.

2.3 Participants in the experiment

A total of 17 experiment subjects aged 20~30 participated. The average age of the participants was 27.4 (SD=3.4) and nine were male while eight were female. The criteria to select experiment subjects were: having driving experience, not having physical problem in operating switches by fingers, and not having cognitive problems for tactile sense and evaluation.

2.4 Experimental environment

In this study, a driving simulator was used to copy the actual car environment. The driving simulator was composed of PNS holder and 27" monitor, steering wheel, accelerator and brake pedals, and gear transmission. The seat position could be freely changed. In the driving simulator, driving scenario was not provided to prevent impairing tactile sensibility, which can be generated by driving task, considering the characteristics of experiment that is the evaluation of the tactile satisfaction of operation. Further, according to preceding researches that drew an optimum operation panel, the best position of operation panel is at the center fascia at the vision allotment. Cognitive aspect of safety and most of the functions are allocated at the center fascia by finished cars manufacturers. Therefore, the evaluation position inside the car was fixed at center fascia (Dukic et al., 2005). A separate frame was then fabricated so that switch could be constructed at the center fascia and the switch could be fixed. Seat was placed at H-30 which was fixed at 270mm since the height in sedans is 240mm and that in SUV is 305mm. The position of center fascia switch was located at 300mm from the seat since the optimum position of switch is middle and lower point of center fascia during simple operation (Park et al., 2013; Aoki et al., 1999). In addition, the distance was adjusted so that individual driver could reach to switches, considering the difference in gender and individual physical characteristics of the participants. The reach between experimental subjects and switch was a maximum of 640mm, a minimum of 480mm, and an average of 560mm. Figure 3 shows the experimental environment.

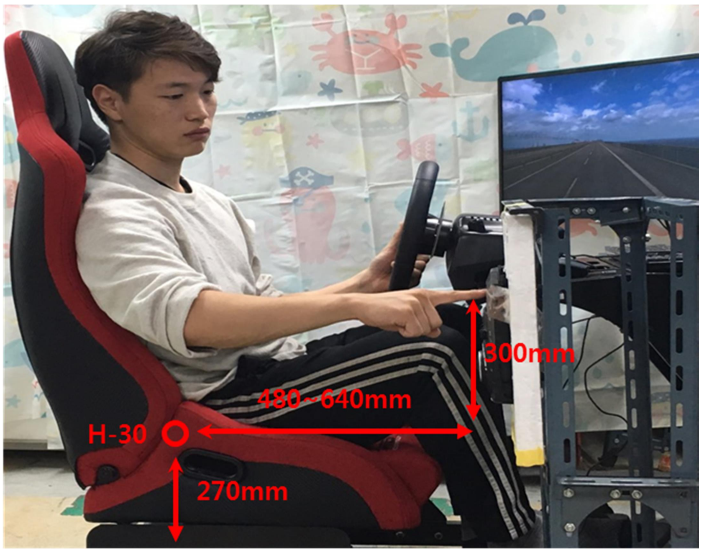

Figure 3. Picture showing the experimental environment

2.5 Experimental procedure

The experimental stages in this study are categorized into preparation stage, practice stage, testing stage, and evaluation stage. During preparation stage, participants operated for each alternative in the driving simulator which is similar with the objective of the experiment and environment inside the car to improve subjective satisfaction generated by operating switch alternatives on which two parameters of angle and curvature were reflected. Sufficient explanation was also given so that participants could sufficiently understand experimental procedure for the subjective evaluation. Participants were asked to prepare their basic information such as their name, age, and driving experience as experimental subjects.

During practice stage, sufficient time was given for 30 alternatives on which six levels of angle and five types of curvature removed the learning effect that occurred during experiment, so that participants could sufficiently feel the tactile difference of the overall satisfaction of operation that was generated by each switch. In the experiment and evaluation stages, the order of switch that had to be operated by each individual participant was decided to control effect by external factors that can be generated during evaluation by using Latin square randomization test planning. The next stage was composed of operating the push switch located at the center fascia. The participants went through the experiment for one alternative and evaluated the satisfaction of operation. A total of 30 trials and evaluation were repeated. During this stage, since a separate driving scenario was not provided to the participants, they were asked to operate the switches with speed and force similar to pressing the action of the switch of actual cars as close as possible after confirming the location of switch by eyes before pressing the switches. When the switch was pressed wrongly, the participant was asked to press that alternative again from the beginning so that error was not allowed.

During evaluation, a 7-point scale was used to evaluate the overall satisfaction of operation generated by tactile difference by each alternative. Whenever the switch per each alternative was pressed, repetitions around 4~6 times were allowed so that the reliability of the subjective evaluation was raised. To prevent a slowdown of tactile sense, a break of around five minutes was given after operation and evaluation for ten alternatives, which made up a total of two times during experiment for 30 types of alternatives.

3. Results

In this study, analysis of variance (ANOVA) for repeated measurement was performed using IBM SPSS Statistics 23 to investigate if two factors significantly affected the satisfaction of operation of the switches. The results showed that both angle ($F(5,80) = 9.628$, $p = 0.000$) and curvature ($F(4,64) = 18.595$, $p = 0.000$) generated significant difference in the satisfaction of operation with a significance level at 0.05. Angle showed high satisfaction of operation in the order of 15°, 20°, 5°, 10°, 0°, and 25°, while in terms of height of the arc, satisfaction of operation was in the order of -1.25mm (concave), -2.5mm (concave), 0mm (flat), 1.25mm (convex), and 2.5mm (convex). LSD post-hoc analysis results showed that a switch angle of 15° was categorized as group A which had the highest satisfaction of operation. Also, 5°, 10°, and 20° were categorized as group B, and 0° and 25° as group C, which had the lowest satisfaction of operation.

In case of curvature, when height of arc was -1.25mm (concave), satisfaction of operation was highest, thus designated as group A, -2.5mm (concave) as group B, and 0mm (flat) and 1.25mm (convex) were designated as group C. A height of 2.5mm radius (convex) was categorized as group D which had the lowest satisfaction of operation. Meanwhile, there was no significant difference found in the interaction between angle and curvature ($F(20,320) = 1.228$, $p = 0.229$). Multiple regression analysis with two factors of angle and curvature as independent factors, along with satisfaction of operation as dependent factors to carry out modeling, showed that the constant was 3.725, coefficient by angles was 0.003, and coefficient by curvature was -0.388. This relationship can be expressed as the following equation.

$$\text{Satisfaction of Operation} = 3.725 + 0.003_{\text{Angle}} + -0.388_{\text{Curvature}}$$

Standardization coefficient in multiple regression analysis and curvature affected more the satisfaction of operation than angle

Table 2. Summary of the ANOVA result of satisfaction of operation

Source	SS	DF	MS	*F*	*p*-value
Angle	91.992	5	18.398	9.628	0.000^{***}
Error (Angle)	152.875	80	1.911		
Curvature	307.165	4	76.791	18.595	0.000^{***}
Error (Curvature)	264.302	64	4.130		
Angle x Curvature	19.400	20	.970	1.228	0.229
Error (Angle x Curvature)	252.733	320	.790		

$^{***}p < 0.001$

Table 3. Result of multiple regression analysis

Source	Unstandardized coefficients		Standardized coefficients	R^2
	B	Standard error	Beta	
Constant	3.725	0.202		0.575
Angle	0.003	0.013	0.024	
Curvature	-0.388	0.064	-0.758	

does. Here, the explanatory power of the model is $R^2 = 0.575$. Table 2 shows the analysis of variance for repeated measurement, while Table 3 shows multiple regression analysis results. Figure 4 and Figure 5 show the LSD post-hoc analysis results.

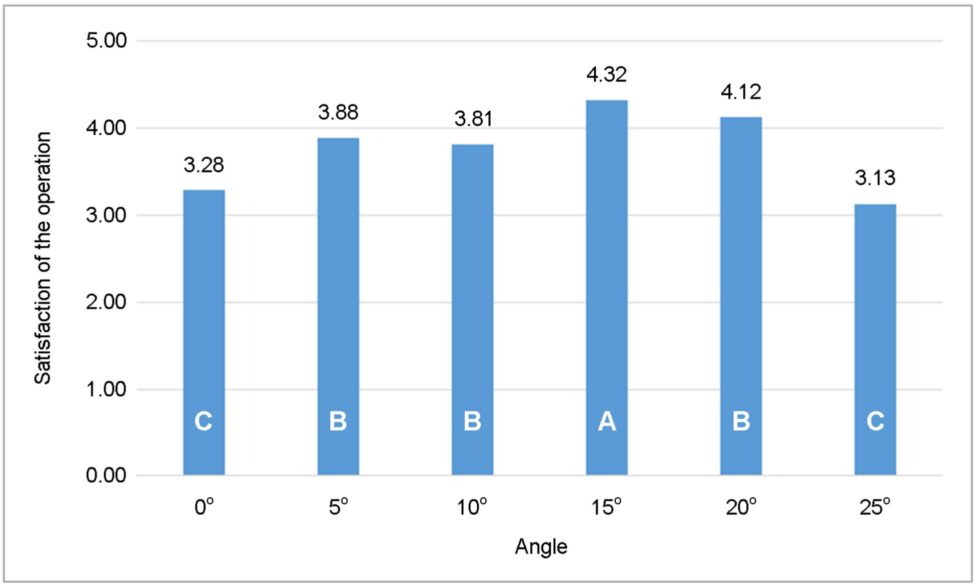

Figure 4. Result of LSD post-hoc analysis (for angle)

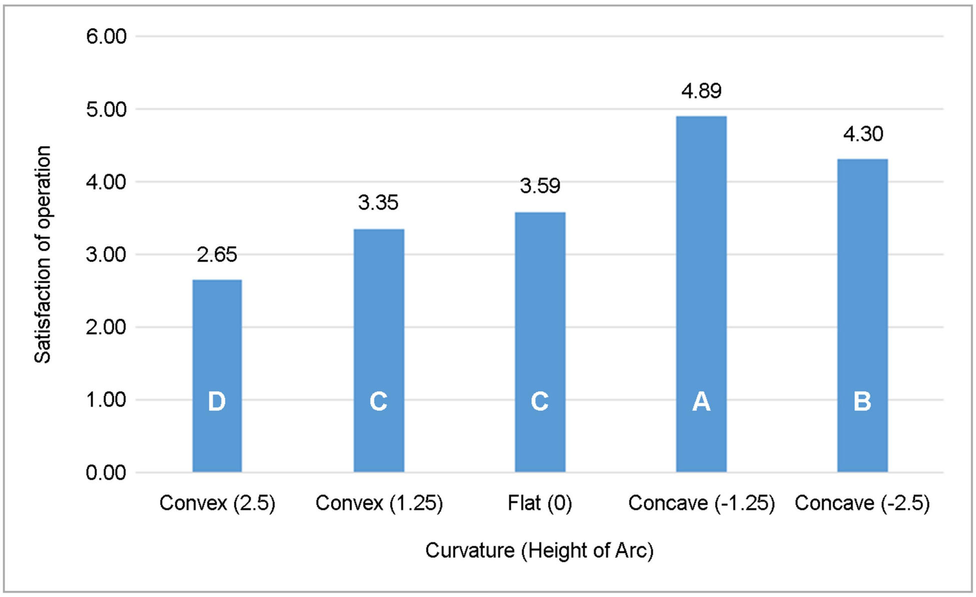

Figure 5. Result of LSD post-hoc analysis (for curvature)

4. Discussion and Conclusion

Push switch is widely utilized in various fields like the industrial environment or our daily routine. The preceding researches on environments inside cars focused on internal factors like operating force or operating switches. However, preceding researches about external shape that plays a role on contact points that directly interact with users in HMI of cars and can affect the feel of operation for switches are lacking. Therefore, this study aims to propose external factors which need to be considered during switch designing to raise the feel of operation under push switch interaction inside the cars. Optimum alternatives are thus proposed. We discuss the study results with preceding researches and theoretical background. The analyzed results are as follows.

Preceding researches showed that the external shape of the switch affects the fatigue of hands, pressing power, or preference in various environments such as industries and offices. Based on research outcomes, the factors that affected the feel of environment inside the cars among external factors of switch were selected. The selected factors were inclined angle of switch from the car center fascia and curvature of the switch such as convex, flat, and concave degrees of surface of the switch (Choi et al., 2015). Analysis of variance was performed to analyze the effect of these two factors on the satisfaction of operation. The ANOVA results showed that both angle and curvature significantly affected the feel of operation of switches. Users preferred a more concave-type of curvature, which was in good agreement with preceding researches that concave switch was more suitable to users under various environments and gave a feeling of well-adjustment to hands (Stanton, 1997; O'Hara et al., 2002). Satisfaction of operation was largely increased till switch angle at 15° followed by decreases from 20°.

The results were similar with preceding researches which drew the effect of force and angle of switch on the feel of operation (Park and Jung, 2014). Further, in the interview with participants, satisfaction of operation was more with the concave-type of switch curvature rather than angle. *F* values of angle and curvature in the ANOVA showed that angle was found to be 9.628, while curvature was 18.595, revealing a difference of around 9. It seems that curvature affected the feel of operation more than angle, among the external factors. It might be because the ends of human fingers are round in shape, so there was more comfort with pressure from a concave-shaped switch. Further, multiple regression analysis was performed for the modeling of satisfaction of operation by the users.

The standardization coefficient was found to be 0.024 for curvature, while it was -0.758 for angle, showing that curvature affected more the satisfaction of operation than angle based on results from ANOVA. Therefore, curvature would have to be considered on a priority basis when switch in the car is designed to improve satisfaction of operation. R^2, which is an explanatory power of model in the multiple regression analysis, was found to be 0.575, which was not that high for the model. It might be because satisfaction of operation was dropped from 15°, while it declined from -1.25mm for curvature, thus both two factors were not linearly related with satisfaction of operation. Angles of 20° and 25° and a curvature of -2.5mm, at which satisfaction of operation was decreased, were excluded and multiple regression analysis was performed. R^2 became 0.884, and the explanatory power of the model became significantly high.

Interaction between two factors (i.e., angle and curvature) was found to be insignificant. Therefore, the most optimum alternative for the external shape of the switch considering the two factors would turn out to be a combination of optimum values of each factor. Post hoc analysis results revealed that a group with the height of the arc at -1.25mm (concave) yielded the highest satisfaction of operation, while it was at 15° for angle. Therefore, external shape and angle of switch that was located at the center/lower end of center fascia inside the care needed to be designed as a little concave and 15°.

The factors that affected the tactile sense of the center fascia of the cars were categorized into internal factor and external factor. Preceding research and the results by this study suggested that design was to be guided as to make peak force at 2.5~3.5N, drop force at 1.00~1.75N, stroke at 0.65~1.15mm, angle at 15°, and curvature at -1.25mm for the optimum satisfaction of operation of cars' center fascia. Further, there can be materials which can affect the satisfaction of operation for the tactile switch. Accordingly, research about the physical characteristics of switch materials such as hardness and roughness would be required.

In this study, experiment for the external factors of switch directly contacted was done by reflecting on the actual interaction between car switches and users in the operation environment inside the cars. Both curvature and angle significantly affected the satisfaction of operation. Curvature was found as a more important factor affecting the feel of operation. Further, the optimum alternative was drawn by combining two factors. These results were meaningful by proposing a guideline for switch design in the center fascia. The result of this study could be utilized as basic data for switch design, and is expected to be applied in switch design in various industries similar to the environment inside the cars.

As number of cars increased, the switch for operating function is increased not only in the center fascia but also in the steering wheel and center console. A gage cluster is expected to be expanded to important information display fields in the near future. Therefore, the importance of switch at various package positions such as steering wheel and center console seems to increase. However, in this study, various package positions inside of cars such as center console, steering wheel, crash pad, door trim were presented. Moreover, since the physical characteristic value of the internal factors of switch affects the satisfaction of operation, this study has a limit in providing results while considering only external factors. Therefore, researches consider the effects of internal and external variables, their interactions are required in the future, and results should be drawn at various package locations. Further, this study sets satisfaction of operation as a dependent variable so that research scope is limited within a tactile sense. However, satisfaction for the switch by the users in the environment inside the car is expected to be changed, largely depending if concept compatibility is satisfactory not only in terms of tactile factor but also visual aesthetic factors and a user's mental model. Therefore, overall research for car switches is required in future. For this, a study that combines external shape by function, tactile factor, and visual aesthetic factor, considering the concept compatibility of increase and decrease in the execution of function in cars, is necessary.

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