An Empirical Analysis of the Design Variables affecting User Satisfaction for the Operation of Automotive Switch

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Abstract
The aim of this research is to figure out design variables that have an effect on user satisfaction for the operation of automotive switch and to investigate the relative importance of the variables and the utility of attribute level. To achieve these goals, an empirical evaluation was made through operating of automotive switches. First, five design variables were selected for the external design elements and the internal design variables of switch were chosen based on the opinions of design experts and previous studies. Next, an experiment was designed using the fractional factorial design for 18 alternatives by 5 design variables (stroke, peak force, drop force, angle of surface, and curvature) that affect user satisfaction. Then, the level of satisfaction of each alternative were evaluated on 100-point scale by 22 subjects. Finally, ANOVA was conducted to verify the significant level of the 5 design variables of the automotive switch. A conjoint analysis was used to investigate the relative importance of each design variable by the utility of attribute level. As a result, the design variables turned out to be of significant importance. Moreover, the result showed relative importance for each design variable and utility of attribute level. It is expected that the results of this study could be utilized to improve the affective quality of the automotive switch.

Keywords: Haptic perception, Feel of switch operations, Automotive switch, Conjoint analysis

Introduction
As the market competition becomes fiercer than ever, product performance and quality no longer can be a source of competitiveness, as their standards increased accordingly in the industry. Therefore, the paradigm of product development has shifted to understand customer preferences primarily and then reflecting them when developing a new product [1, 2]. Following this paradigm, the automotive industry is trying to increase customer satisfaction by reflecting their preferences not only in the exterior and interior design but also in the HMI(Human-Machine Interaction) process, between the driver and the automobile [3, 4].

Currently the HMI between driver and automobile is composed of not only the touch screen but also physical switch such as the knob or the push button [5]. Recently, touch screen has been widely used in automobile HMI but depends highly on the visual aspect and can trigger distraction while driving since blind control is difficult [6]. Thus, physical switch, which is controlled intuitively and whose clear force feedback is available, has been widely used for the safety of drivers.

Previous studies on control sensitivity related to existing automobile switches suggested research that only reflected the design characteristics of the switch’s interior [7, 8, 9, 10]. In order to clearly understand user’s switch control sensitivity, however, further research that considers the external factors rather than only the internal design characteristics is necessary.

Therefore, in this research tries to find out that factors influencing the feel of switch operations, by considering both the interior and exterior design characteristics of the switch, and identify the relative importance among design variables.

Method
Subject
A total number of the subject who participated in this experiment was 22. Their age distribution was 15 people in their 20’s, and 7 in their 30’s, with the average of 29.2 years old. The subject were 11 me and 11 women. Subjects were selected among those who had driving experience, had no problem operating the switch, and had normal sense of touch.

Variables
In previous studies, there were 3 internal variables of the switch that influenced the feel of switch operations; peak force (maximum pressing force), drop force (difference between peak force and the force at switch point of contact), and stroke (depth of switch point of contact) [10]. After the FGI (Focused Group Interview) with users that have tried the previous switch, curvature and angle of surface have been derived as the external design variables that influence on the feel of switch operations. Curvature refers to the flatness and roundness of switch in the flat surface, which is the curvature in the flat surface. Since the size of switch is fixed, curvatures at the two fixed points are determined by the radius in between two fixed points and the center of circle which is 1/R [11]. Angle of surface is defined by the angle between the switch and surface (Figure 1).
After studying previous documentary research about peak force, drop force, and stroke’s physical characteristic value range, it turns out that peak force was 2.5N~4.5N, drop force was 0.25N~1.75N and stroke was 0.25mm~1.65mm [10]. Through the research on various switch modules on curvature and angle of surface’s physical characteristic value range, it turns out that curvature was 0 ~ 0.125, and angle of surface with 0° ~ 16° (Table 1).

| Design variables | Physical characteristics |
|------------------|--------------------------|
| Stroke           | 0.25mm ~ 1.65mm          |
| Peak force       | 2.5N ~ 4.5N              |
| Drop force       | 0.25N ~ 1.75N            |
| Angle of surface | 0° ~ 16°                 |
| Curvature        | 0 ~ 0.125                |

In addition, satisfaction of the operation of automotive switch was selected as a dependent variable to figure out the correlation of each alternative and the feel of switch operations. Satisfaction was assessed through a 0 to 100 scale and was used for the result analysis.

### Table 2. Details of experimental alternative

| No | Stroke (mm) | Peak force (N) | Drop force (N) | Angle of surface (°) | Curvature |
|----|-------------|----------------|----------------|----------------------|-----------|
| 1  | 1.15 ~ 1.65 | 3.5 ~ 4.5      | 1.00 ~ 1.75    | 0                    | 0.125     |
| 2  | 1.15 ~ 1.65 | 2.5 ~ 3.5      | 0.25 ~ 1.00    | 8                    | 0.083     |
| 3  | 1.15 ~ 1.65 | 2.5 ~ 3.5      | 1.00 ~ 1.75    | 16                   | 0.000     |
| 4  | 0.65 ~ 1.15 | 3.5 ~ 4.5      | 0.25 ~ 1.00    | 0                    | 0.000     |
| 5  | 1.15 ~ 1.65 | 2.5 ~ 3.5      | 1.00 ~ 1.75    | 16                   | 0.000     |
| 6  | 1.15 ~ 1.65 | 2.5 ~ 3.5      | 0.25 ~ 1.00    | 0                    | 0.000     |
| 7  | 0.25 ~ 0.65 | 3.5 ~ 4.5      | 1.00 ~ 1.75    | 8                    | 0.000     |
| 8  | 1.15 ~ 1.65 | 3.5 ~ 4.5      | 1.00 ~ 1.75    | 16                   | 0.000     |
| 9  | 1.15 ~ 1.65 | 3.5 ~ 4.5      | 0.25 ~ 1.00    | 8                    | 0.125     |
| 10 | 0.25 ~ 0.65 | 2.5 ~ 3.5      | 0.25 ~ 1.00    | 0                    | 0.000     |
| 11 | 1.15 ~ 1.65 | 2.5 ~ 3.5      | 1.00 ~ 1.75    | 16                   | 0.083     |
| 12 | 0.25 ~ 0.65 | 3.5 ~ 4.5      | 1.00 ~ 1.75    | 0                    | 0.083     |
| 13 | 0.25 ~ 0.65 | 2.5 ~ 3.5      | 0.25 ~ 1.00    | 16                   | 0.125     |
| 14 | 0.65 ~ 1.15 | 3.5 ~ 4.5      | 0.25 ~ 1.00    | 16                   | 0.083     |
| 15 | 1.15 ~ 1.65 | 3.5 ~ 4.5      | 0.25 ~ 1.00    | 0                    | 0.000     |
| 16 | 1.15 ~ 1.65 | 2.5 ~ 3.5      | 1.00 ~ 1.75    | 0                    | 0.083     |
| 17 | 1.15 ~ 1.65 | 2.5 ~ 3.5      | 0.25 ~ 1.00    | 0                    | 0.125     |
| 18 | 1.15 ~ 1.65 | 2.5 ~ 3.5      | 0.25 ~ 1.00    | 0                    | 0.083     |
Experiment on 18 different switch alternatives was conducted on top of the seating buck in order to provide similarity to that of the actual operating environment. Also, the location of the switch on the seating buck was fastened in order to evaluate based on the center of automobile center fascia.

Figure 2. Printed circuit board and Switch assembly

Experimental Procedure
Before conducting a following experiment, we took enough time to explain the purpose and procedures of the experiment to participants. Not only that, but we also conducted a pre-test to find out whether the subjects have problems with their sense of touch on the evaluation switch or not. Then, we allowed subjects to be aware of the difference in the sense of touch between each alternative, and we gave them enough time to experience how switches operate before evaluation in order to remove learning effect during the experiment. In the evaluation stage, the testing sequence was changed equally to offset the effects caused by different sequences, which is counter balancing.

Result
ANOVA Analysis
In order to find out whether or not different variables affected the feeling of switch operations, ANOVA was used. In the ANOVA result, it were all statistically significant at α=0.05. Accordingly, all 5 different variables showed that they had significant difference on the feel of switch operations (Table 3).

Conjoint Analysis
In this experiment, we have conducted conjoint analysis on the evaluation result to reveal the relative importance of 5 different design variables: stroke, peak force, drop force, angle, and curvature, which influences the feel of switch operations and to derive the optimal level.

In the conjoint analysis result, the person’s R value toward the survey made in 100-point scale to see the relevance of model, showed that the model was relevant with a value of 0.614. On the design variables’ relative importance which influences user’s satisfaction, stroke turned out to be the highest with 26.1%, next was angle with 25.5%, curvature with 19.4%, peak force with 15.0%, and drop with 14.0%. Also, after checking the optimal utility value in order to find out the optimal level for each design variables, utility value of stroke was highest with 11.704 at 0.65 ~ 1.15 mm, utility value of angle was 11.241 at 8°, utility value of curvature was 6.983 at 0.083, utility value of peak force was 6.593 at 2.5 ~ 3.5 N, and utility value of drop force was 6.335 at 1.00 ~ 1.75 N (Table 4).

| Source     | SS   | DF | MS | F-value   | p-value |
|------------|------|----|----|-----------|---------|
| Stroke     | 7658.4 | 2  | 3829.2 | 76.9 | 0.000*   |
| Peak force | 263.7  | 1  | 263.7 | 5.3  | 0.022*   |
| Drop force | 3933.1 | 1  | 3933.1 | 79.0 | 0.000*   |
| Angle      | 4525.3 | 2  | 2262.7 | 45.4 | 0.000*   |
| Curvature  | 15811.0 | 2 | 7905.5 | 158.7 | 0.000*   |
| Error      | 18877.5 | 379 | 49.8 |         |         |
| Total      | 1247609.0 | 396 | 49.8 |         |         |

* : Significant at α=0.05

Discussion and Conclusion
In this experiment, we have looked at the relationship between subjective satisfaction that a user feels in the vehicle switch interaction, and the design variables. We also suggested the relative importance that needs to be considered when designing the switch. For this matter,
the summary that was analyzed by comparing this research with preceding researches and theories is as follows.

First, we selected stroke, peak force, drop force, angle of surface, and curvature as variables which influence on the feel of switch operations based upon previous studies, opinions of design experts, and the FGI as background research. Next, in order to find out whether these design variables influence on the feel of switch operations, we have conducted ANOVA. In the ANOVA at the 0.05 significance level, all 5 different variables which are stroke, peak force, drop force, angle, and curvature showed significant difference on the feel of switch operation. Accordingly, not only the internal design variables which were found in the previous studies, but also the external design variables are highly probable to influence user’s satisfaction.

Furthermore, we have conducted a conjoint analysis on the evaluation result in order to reveal the relative importance of 5 different design variables: stroke, peak force, drop force, angle, and curvature which influences on the feel of switch operations and to derive optimal level. As a result, on the design variables' relative importance which influences user's satisfaction, stroke was highest with 26.1%, next was angle with 25.5%, curvature with 19.4%, peak force with 15.0%, and drop with 14.0%. This showed equivalent result to that of switch internal design variables' relative importance order. Stroke and angle seemed to be important factors that need to be considered when designing the switch. Then the curvature, peak force, and drop force follows in rank.

Lastly, after checking the optimal utility value in order to find out the optimal level for each design variables, utility value of stroke was highest with 11.704 at 0.65 ~ 1.15mm, utility value of angle was 11.241 at 8°, utility value of curvature was 6.983 at 0.083, utility value of peak force was 6.593 at 2.5 ~ 3.5N, and utility value of drop force was 6.335 at 1.00 ~ 1.75N. Therefore, it is necessary to consider design standards as listed above when designing the automobile switch in order to improve user's operating affective quality.

In this experiment, we applied various design variables to create a realistic interaction circumstance. However, limitations exist. First, we have not figured out the influence toward interaction among the aforementioned variables. In addition, we only provided evaluation results in a limited location, since we have not considered various package locations in the evaluation of automobile switch. Therefore, in future studies, important variables should be selected so that a more exact relationship among variables could be identified, and consideration on package location is necessary. This study is expected to be used as a basis of automobile switch design and to help management on operating affective quality.

This study result may be used as basic information in the design for automobile switch and is also expected to be useful for management on operating affective quality.

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