Investigation of Operating Forces of the Automotive Tactile Switch regarding Various Positions

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Abstract
The objective of this study is to investigate affective preference of the automotive tactile switch which influences package controllability and user satisfaction. In order to accomplish this objective, the independent variables for this experiment were package location (door trim, crash pad, steering wheel (L), steering wheel (R), center fascia, center console and overhead console) and operating force (1.5N, 2.0N, 2.5N, 3.0N and 5.0N). Furthermore, we constructed an automotive seating buck based on actual location data for switch assemblies that consisted of similar tactile switches. Then we measured affective preference on the operating force for each switch in each package location on a 7 point Likert scale. The ANOVA results for affective preference on the whole package location categorized the package locations into three groups for driver behavior: tapping zone, reaching zone and grasping zone. SNK posthoc-analysis revealed that the tapping zone showed that the operating force preferred by the users was 2.0N and 2.5N. The results for the reaching zone showed that users preferred the 3.0N operating force while the results for the grasping zone showed preference for the 3.0N and 5.0N operating forces. We expect the results of this study to be utilized to improve the affective quality of the automotive tactile switch.

Keywords: Automotive tactile switch, Affective preference, Package location, Operating force, driver’s behavior

1. Introduction

Although the primary task of driving is the most crucial, the importance of the secondary task of using the IVIS (In-Vehicle Information System) is steadily increasing [1]. Therefore, interaction design between the driver and IVIS has a large influence over safety and affective quality. Due to increased application of various switches to the automobile interior, there should be a human factors evaluation. The design of the switch should consider reducing distractions to the driver to prevent accidents and increasing driver convenience while operating switches.

In a highly competitive automobile industry, a primary requirement for product development is the accurately assessed user needs and preference [2, 3, 4]. There should be an understanding between user preference and physical switch characteristics in order to design a user-centered switch.

An important parameter of switch design is determining the peak operating force while operating the switch [5]. While the switch is being pressed, operating force consistently rises until a peak force is reached. Then, the operating force suddenly declines until the user recognizes activation/deactivation of the function [6].

Previous studies usually examined specific locations without considering of the whole package location [7, 8]. Therefore, a further study is required to integrate these findings for a more accurate and complete analysis of user preference.

This study analyzed the preference on operating forces for each switch assembly in each package location to develop an accurate assessment of the whole package location. The results showed that preference of switch operation for certain package locations had a specific user preference based on the user’s behavior.

2. Method

2.1 Subjects
Fourteen subjects participated in this study. The average age was 29 (SD=3.4) years old. There were 8 males and 6 females. There were 12 right-handed and 2 left-handed participants. The participants had no physical disabilities or nerve damage to impair switch
2.2 Experimental design

There were two independent variables in this study. The first was the package location of the automobile interior. There were 7 different package locations for the driver to test: door trim, crash pad, steering wheel (L), steering wheel (R), center fascia, center console and overhead console. The package location was chosen as an independent variable to measure the different results of driver preference due to the variation caused by the distance away from the driver and driver behavior. The second independent variable was the operating force of the tactile switch. The operating force was determined by the peak force required to operate the tactile switch. There were five different operating forces: 1.5N, 2.0N, 2.5N, 3.0N and 5.0N.

The dependent variable in this study was driver’s affective preference for the tactile switch. Each package location had different tasks which were individually rated on a 7 point Likert scale where 7 stood for the highest user satisfaction.

2.3 Experiment apparatus and Environment

This study utilized an Alps Co. surface mount type tactile switch with the SKPM (1.5N, 2.0N, 2.5N, 3.0N) series and the SKPR (5.0N) series as shown in Figure 1.

![Figure 1. SKPM and SKPR series](image)

Since the experiment was conducted to measure the affective preference of operating force, the shape of the tactile switches, external design, and internal structure of the switch assembly were similar to reduce the confounding factor as shown in Figure 2.

![Figure 2. External design, and internal structure of the switch assembly](image)

However, the operating force of each tactile switch was altered on the PCB to measure the driver’s affective preference of operating force as shown in Figure 3.

![Figure 3. Tactile switches on the PCB](image)

A seat-buck was used to simulate an actual automobile interior environment based on location data. The switch assembly was fixed to each package locations.

2.4 Tasks and Procedure

There were four steps in this experiment: preparation, practice, main experiment and evaluation. While the preparation for this experiment was only conducted once, the practice, main experiment, and evaluation steps were conducted seven different times according to package location. There were 35 (7 package location × 5 operating force) tasks for the participants to rate. The order of evaluation was mixed for counterbalancing. The preparation was performed to explain the type of tasks and the experimental objective. In addition, a pre-test was conducted to determine if participants could distinguish a just noticeable difference (JND). The practice session was to familiarize participants with the switches at the package locations. In the main experiment, participants were instructed to only press certain switches in a designated labeled area with a speed consistent to switch operation while driving. Afterwards, participants were instructed to evaluate on the different tactile switches on a 7 point Likert scale. The participants were given a short break after each package location evaluation so that sensitivity did not diminish.

3. Results

3.1 Affective preference

3.1.1 Affective preference of the whole package location

On a significance level of α=0.05, analysis of variance for affective preference for the 7 package locations and 5 operating forces were all found to be significant (P<0.001). The interaction between package location and operating force was also found to be significant (P<0.001).

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Package location</td>
<td>6</td>
<td>32.992</td>
<td>5.499</td>
<td>7.730</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Operating force</td>
<td>4</td>
<td>526.110</td>
<td>131.528</td>
<td>184.911</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Package location *Operating force</td>
<td>24</td>
<td>316.947</td>
<td>13.206</td>
<td>18.566</td>
<td>&lt;.001*</td>
</tr>
</tbody>
</table>

* significant at α=0.05

Since this interaction was significant, there were further examinations to discover the cause as shown in Figure 4. The affective preference of operating force was examined for each package location. This resulted in a discovery of a similar pattern for driver behavior. Therefore, the package locations were classified into
three groups: tapping zone (door trim, center console), reaching zone (crash pad, center fascia, overhead console), grasping zone (steering wheel (L), steering wheel (R)).

Figure 4. Interaction profile chart between operating force and package location

3.1.2 Affective preference of the tapping zone

Regarding the tapping zone, on a significance level of \(\alpha=0.05\), analysis of variance for affective preference for operating force was found to be significant (\(P<0.001\)). However, package location (\(P=0.303\)) and the interaction between package location and operating force (\(P=0.170\)) were both not significant.

Table 2. ANOVA table for affective preference of the tapping zone

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Package location</td>
<td>1</td>
<td>0.714</td>
<td>0.714</td>
<td>1.069</td>
<td>0.303</td>
</tr>
<tr>
<td>Operating force</td>
<td>4</td>
<td>235.043</td>
<td>58.761</td>
<td>87.948</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Package location * Operating force</td>
<td>4</td>
<td>4.357</td>
<td>1.089</td>
<td>1.630</td>
<td>0.170</td>
</tr>
</tbody>
</table>

SNK posthoc-analysis showed that the affective preference on operating force regarding the tapping zone was separated into three groups as shown in Figure 5. The first group was labeled A which consisted of 2.5N with a score of 5.6 and 2.0N with a score of 5.4. The second group was labeled B which consisted of 3.0N with a score of 5.9. The third group was labeled C which consisted of 1.5N with a score of 2.8 and 5.0N with a score of 2.4.

Figure 5. Affective preference for operating force regarding the tapping zone

3.1.3 Affective preference of the reaching zone

Regarding the reaching zone, on a significance level of \(\alpha=0.05\), analysis of variance for affective preference for operating force was found to be significant (\(P<0.001\)). However, package location (\(P=0.537\)) and the interaction between package location and operating force (\(P=0.720\)) were both not significant.

Table 3. ANOVA Table for Affective preference of the reaching zone

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Package location</td>
<td>2</td>
<td>0.433</td>
<td>0.714</td>
<td>0.625</td>
<td>0.537</td>
</tr>
<tr>
<td>Operating force</td>
<td>4</td>
<td>79.131</td>
<td>58.761</td>
<td>114.059</td>
<td>&lt;.001*</td>
</tr>
<tr>
<td>Package location *Operating force</td>
<td>8</td>
<td>0.463</td>
<td>1.089</td>
<td>0.668</td>
<td>0.720</td>
</tr>
</tbody>
</table>

SNK posthoc-analysis showed that the affective preference on operating force regarding the reaching zone was separated into five groups as shown in Figure 6. The first group was labeled A which consisted of 3.0N with a score of 5.9. The second group was labeled B which consisted of 2.5N with a score of 5.3. The third group was labeled C which consisted of 2.0N with a score of 4.0. The forth group was labeled D which consisted of 5.0N with a score of 3.2. The fifth group was labeled E which consisted of 1.5N with a score of 2.6.

Figure 6. Affective preference for operating force regarding the reaching zone

3.1.4 Affective preference of the grasping zone

Regarding the grasping zone, on a significance level of \(\alpha=0.05\), analysis of variance for affective preference for operating force was found to be significant (\(P<0.001\)). However, package location (\(P=0.265\)) and the interaction between package location and operating force (\(P=0.518\)) were both not significant.

Table 4. ANOVA Table for Affective preference of the grasping zone

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Package location</td>
<td>1</td>
<td>0.864</td>
<td>0.864</td>
<td>1.107</td>
<td>0.295</td>
</tr>
</tbody>
</table>
SNK posthoc-analysis showed that the affective preference on operating force regarding the grasping zone was separated into four groups as shown in Figure 7. The first group was labeled A which consisted of 3.0N with a score of 6.3 and 5.0N with a score of 6.1. The second group was labeled B which consisted of 2.5N with a score of 4.9. The third group was labeled C which consisted of 2.0N with a score of 3.7. The forth group was labeled D which consisted of 1.5N with a score of 2.5.

4. Discussion and Conclusion

This study conducted tests in a seat-buck to recognize the user preference on operating force for each switch assembly in each package location. The seat-buck had 7 different package locations, each with a switch assembly containing 5 different operating forces. The results of these tests revealed that the preference on switch operation for certain package locations differed following the user preference due to user’s behavior. Furthermore, the user’s behavior pattern was categorized into tapping, reaching and grasping.

There were distinct results based on the user’s behavior pattern. For example, the results for the tapping zone showed that the operating force preferred by the users was 2.0N and 2.5N. The results for the reaching zone showed that users preferred the 3.0N operating force while the results for the grasping zone showed the best preference for the 3.0N and 5.0N operating forces. These results showed that users desired heavy operating force for the grasping zone, a medium operating force for the reaching zone, and the light operating force for the tapping zone. The results of this study can be used to heighten user satisfaction by implementing different operating forces depending on package location.

This study prioritized the user preference on operating force. Future studies could include the examination of the relationship between user preference and stroke (i.e. depth of switch) or the relationship between user preference and switch clicking sound since these factors are also important for developing a user-centered switch.

References