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Analysis of customers' satisfaction with automobile exterior panel stiffness: focus on the hood and doors of mid-sized sedan

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ABSTRACT

The exterior panel is an important part of automobiles because it not only determines the cosmetic appearance but also resists external impacts, and the stiffness of exterior panels is among the survey items in the initial quality study (IQS) by JD Power. This study aims to investigate the effects of the stiffness of exterior panels on customer satisfaction levels because this relationship has not been studied extensively in the field of affective automotive engineering. Four effects were selected for this evaluation of exterior panel stiffness levels: hardness, consistency of deformation, thickness, and associated satisfaction levels. In the experiment, 54 Korean men ranging in age from their 20s to their 50s evaluated three exterior panel parts on nine mid-sized sedans. These parts included the hood, front door, and rear door. The results showed that customer satisfaction levels differed significantly depending on the panels and increased when the stiffness was greater. It was also identified that the participants evaluated panel stiffness levels with a force of up to 14 kgf. Customer satisfaction models were developed with the variables that were found to describe the mechanical properties of the panels. These models will be helpful to people involved in the design and control of the stiffness quality of exterior panels.

Keywords: affective quality, mid-sized sedan, exterior panel, force-deflection curve, perceived stiffness, customer satisfaction.

INTRODUCTION

It is known that considering customer affect is very important when developing a successful product. Customers are influenced by affective and cognitive factors in their product purchase decisions; the former include subjective images and feelings, as influenced by aesthetics, and the latter refer to product functionality and usability (Seva and Helander, 2009). Meeting the requirements of functionality and usability is essential but not always sufficient for a product to succeed, and affective factors are necessary, although they are difficult to quantify (Mondragón et al., 2005; Norman, 2004). Especially in saturated and competitive markets, the functionality and usability of products are often assumed (Kano et al., 1984), and the success of a product is mostly influenced by affective factors (Maslow, 1970; Jordan, 2000; McDonagh et al., 2002).

In the automobile market, customer needs for affective factors and for performance and functionality have been increasing (Kim et al., 2018). When customers are making purchase decisions, performance indices, such as fuel consumption efficiency and horsepower, remain important. However, if the functionality and performance of automobiles are similar, the look and the feel of interior/exterior design factors and materials play crucial roles in purchasing decisions (You et al., 2006). Automobile manufacturers are currently placing greater emphasis on the affective satisfaction of customers and are striving to enhance the affective quality levels of various parts and features of their products (Kim et al., 2018).

Because the exterior panels are one of the many parts of an automobile, their quality is important for both manufacturers and customers. Unexpected or excessive deformation of these panels, which occurs when customers push the panels, can degrade the quality of the automobile in the customer's eyes, and the deflection and dent resistance of exterior panels is included as a survey item on the initial quality studies (IQS) of JD Power. Park et al. (2007) also indicated that the deformation of exterior panels is perceived as a major flaw because such deformation influences the cosmetic appearance of the automobile. Our survey, conducted earlier, also showed that the number of people who consider the stiffness of exterior panel when purchasing a car was more than twice (69%) those who do not (31%).

The exterior panels are typically on the doors, hood, trunk, roof, fenders, and outer sides. The required attributes of exterior panels are stiffness, formability, and aesthetics. They should be sufficiently strong to resist external impacts, should be easy to form, and should be aesthetically pleasing. Sufficient stiffness and good dent resistance are essential quality inspection items (Ekstrand and Asnafi, 1998). To increase the stiffness, thicker panels are required, but they decrease the forming capability, as well as the fuel efficiency, due to their greater weight. Given that the manufacturing cost of exterior panels depends on the materials used, as well as the forming method and thickness, manufacturers are working to develop panels with high stiffness, strength, and dent resistance levels but those are also inexpensive and light.

The sensation of force and weight have been mainly studied in experimental psychology for a long time. It is well known that the perceptions of force and heaviness are primarily derived from centrally generated motor command, and they are partially supported by peripheral sensation originating in the muscles and touch sensation in the skin (Jones, 1986). The ability to distinguish among different forces and weights by voluntary muscular exertion is referred to as the sense of force. Cholewiak et al. (2008) reported that humans could distinguish two or three levels of stiffness within a range of 0.2 to 3.0 N/mm, as well as two or three levels of force ranging from 0.1 to 5.0 N. In addition, it was revealed that there are many visual properties, such as size, material, and color, that influence perceived heaviness (Jones, 1986). Recently, Deng and Kahn (2009) investigated the effect of the image location of snack packages on perceived heaviness and preferences.

Previous studies in the field of automotive affective engineering have investigated the affects related to various sensory modalities, such as the visual, auditory, and tactile modalities, whereas studies have paid little attention to affect related to the sense of force, such as the stiffness of exterior panels. There are several examples of affective studies of each modality. For instance, Jingo and Horacio (1997) and Tanoue (1997) evaluated the visual aesthetics of the interiors of passenger cars, and Parizet (2008) and Poirson (2010) studied door closing and engine sounds. You et al. (2006) surveyed the tactile feelings of interior materials, and Nagamachi (2001) did so for the smells of the interiors of new cars. Previous studies related to the affective quality of exterior panels have focused mainly on visual aesthetic design factors, such as measurement scales for vehicle aesthetics (Chang et al., 2007), systematic design methods related to the exterior appearance of automobiles (Lai et al., 2005), and matching wheel hubs with different types of cars (Luo et al., 2012).

Subjective affects related to the sense of force have mainly studied controllers, such as buttons, keys, and switches. Schutte and Eklund (2005) attempted to relate tactile feelings to the mechanical, electrical, and form designs of rocker switches, but the force factor included in the mechanical designs was insufficiently significant to gain an understanding of touch feelings. In contrast, Ayas et al. (2011), who studied subjective affects related to the force properties of trigger switches of powered hand tools, found a meaningful relationship between the affects and properties. Studies related to keyboard design have analyzed users' typing feelings according to the types of keys (Weir et al. 2004), the reaction force, and the typing depth (Kosaka et al., 2005). It is commonly known that users prefer tactile keys with a marked increase in the level of force at the actuation point, compared to linear keys, and among types of keyboards, the least forceful types are the most popular. Nevertheless, these findings with a small range of force are difficult to connect to the stiffness of exterior panels owing to differences in the context of use and the amount of force involved.

Accordingly, this study aimed to analyze the relationship between the mechanical properties of exterior panels and customers' affects. Specifically, this study addresses whether panels with varying mechanical properties influence customers' affects, i.e., whether customers can distinguish the properties of panels and rate their affective feelings based on these properties, which variables related to the mechanical properties of exterior panels specifically influence their affects, and which properties (or levels) of the panels are preferred by customers. This study was conducted as a semantic differential experiment involving various exterior panels, and it analyzed the relationship between stiffness and the customers' affects based on the resulting empirical data.

BACKGROUND AND THE RESEARCH HYPOTHESES

Generally, stiffness is the resistance of a body deformation, but in the case of panels, it is defined to be resistance to elastic deformation. The stiffness of exterior panels was measured with flexural strength testing on the deflection of the panel, resulting in force-deflection curves (hereafter panel curves), while that of solid objects is usually measured with a tensile (compressive) strength test machine, resulting in stress-strain curves.

The two panel curves in Figure 1 present two variables describing the mechanical properties of exterior panels. The first variable stiffness level of a panel is defined as the slope of the curve dividing an applied force by a deflection as shown in the right curve, and a panel has a higher stiffness level as the slope increases (Ekstrand and Asnafi, 1998). The second variable is related to the interval between the upper and lower critical limits of the left curve, where the panel deflects rapidly with the decrease in required force. Although the required force usually increases as the deflection of a panel increases, the exterior panel with this interval deflects with less force after the upper critical limit. Users who have experienced this interval felt that the panel was very weak and expressed that it was "gelatinous" or "resilient". Auto manufacturers refer to this section as canning, and the second variable of canning size is defined as the force range of the upper and lower critical limits.

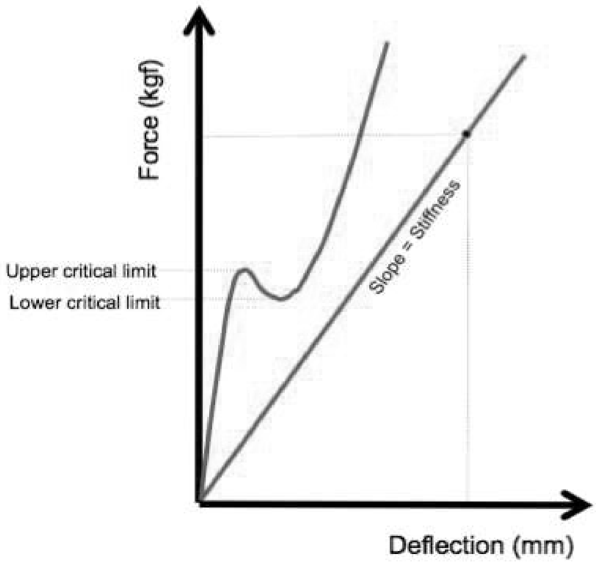

Fig. 1. Illustrated force deflection graph of the exterior panel.

This study sets the following hypotheses based on the above two variables and the research questions established in the Introduction.

H_1: Exterior panels with varying mechanical properties have an effect on customer affect.

H_2: Customers prefer exterior panels with a high level of stiffness.

H_3: The slopes of varying phases (early, middle, and late) of the panel curve have different effects on satisfaction levels.

H_4: Canning has a negative effect on customer satisfaction, but customers cannot perceive a small degree of canning.

Hypothesis H_1 refers to the first research question, and the others pertain to expectations about the second and the third questions. This study assumed that customers' affects differ significantly depending on the exterior panel, with varying properties as in H_1. H_2 refers to expectations regarding the slope of the panel curve (defined as the stiffness level of the panel); i.e., a panel with a high stiffness level is preferred. H_3 is another expectation about the slope of the panel curve, i.e., that the curve slopes of the early, middle, and late phases have different impacts on customers' affects. H_4 is an assumption about the canning size (the second variable), i.e., that the canning influences customer satisfaction negatively as its size increases. Finally, related to the panel curve, the study sought to ascertain the degree of force with which customers evaluate exterior panels and to rate their resulting affects. Korean auto manufacturers typically test the stiffness of exterior panels with force up to 20 kgf, but customers are expected to use less force, as stated in H_5 below.

H_5: Customers evaluate exterior panels with force less than 20 kgf.

METHOD

Participants

In this experiment, 54 Korean males aged from their 20s to their 50s participated. According to Voorbij & Steenbekkers (2001), there is a significant difference between males and females in pushing and pulling forces. Therefore, in this study, the evaluation of the stiffness of the automobile exterior pane was performed only for male. In addition, Barnes et al. (2008) found that involving more than 40 subjects is sufficient for psycho-physical experiments. Because subjective evaluations of affect can differ greatly depending on the individual, only male subjects were recruited to increase the homogeneity among the participants. The range of the subjects' ages adhered to the primary driver age suggestions of Horberry et al. (2008). Of the participants, 25 were in their 20s, 17 were in their 30s, and 12 were older than 40 (Table 1). In addition, 63% of them were employees, and 67% had driving experience of more than one year.

Table 1. Demographics of participant sample.

Variable	Category	Count	% of Total*
Age	21-30	25	46
	31-40	17	31
	41-60	12	22
	Total	54	100
Job	Student	20	37
	Employee	34	63
Driving experience	$0.5 \leq DE < 1$ years	18	33
	$1 \leq DE < 5$	27	50
	$5 \leq DE$	9	17

* % rounded to nearest whole number

Exterior panels and vehicles

The participant evaluated the three parts of exterior panels - the hood, the front door, and the rear door - of nine mid-sized sedans. These panels (see Figure 2) were considered to be major exterior panels, and the selected class of vehicle was the most popular class in Korea. With consideration of the participants' fatigue during the experimental tasks, nine mid-sized sedans were selected. These autos were two Korean sedans (YF Sonata and K7), five Japanese sedans (Camry, Lexus ES 350, Avalon, Maxima, and Accord), one American sedan (Taurus), and one European sedan (Insignia).

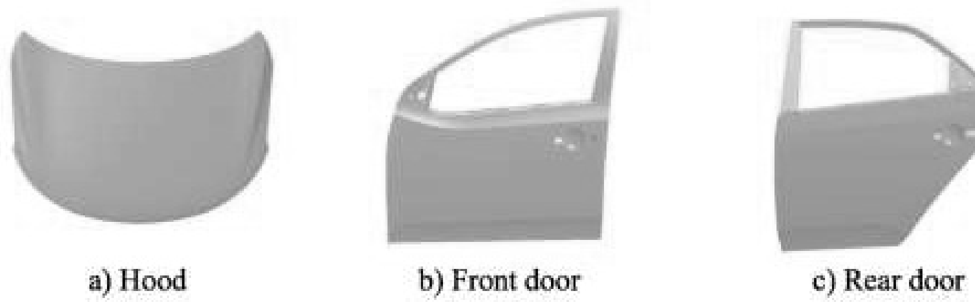

Fig. 2. Parts of exterior panels selected in the experiment.

Mechanical measurements of exterior panel stiffness

The stiffness levels of the hoods, front doors, and rear doors on the nine mid-sized sedans were measured with the help of an auto manufacturer. It is known that panel stiffness levels vary from point to point, being weakest at the center and strongest at the edges of the panels. In this study, the weakest center area served as the measurement point of the panel stiffness, following Ekstrand and Asnafi (1998). The maximum force applied to the panels was restricted to 20 kgf so that the panels could be restored back to their original shapes.

Semantic space of exterior panel stiffness

Affects related to panel stiffness levels were initially surveyed from various sources. These affects including the category of touch-feel evaluations in the Korean vocabulary related to the senses (Jung and Nah, 2007) and image/impression dimensions (Han et al., 2001), as well as affective studies of switches (Schutte and Eklund, 2005; Ayas et al., 2011). The following seven items were investigated: hardness, smoothness, elasticity, safety, anxiety, luxuriousness, and satisfaction.

The applicability of these seven items in an evaluation of exterior panel stiffness levels was assessed in a preliminary experiment, in which ten male students rated the effects of the three panel parts on nine vehicles using a seven-point semantic differential scale. The preliminary experiment required an hour, and the participants reported that their level of fatigue when pushing the panels to rate their stiffness levels was not overly high to interference with the evaluation in this time period. In the analysis of the experimental data, satisfaction and luxuriousness were highly correlated with each other with a correlation coefficient of 0.94; hence, satisfaction, which represents the overall level of affect, was selected for the main test. The item of hardness was also selected because it is directly related to the slope of the panel curve. However, the items of safety and anxiety were discarded because they were ambiguous when rating the panels and were comprehended differently among the subjects. In other words, some of the participants considered these items to be intended for drivers, while others considered them to be intended for pedestrians. The items of smoothness and elasticity were also difficult to use in the evaluation, considering that the solidity of the panels did not differ statistically, depending on the exterior panel in question ($\alpha = 0.05$). Instead, the study added two new items related to the mechanical properties, explaining the exterior panel stiffness. The item “consistency of deformation” was selected because it is related to the canning size, and “thickness” was also selected based on the idea that customers mentioned this item in relation to the stiffness of the exterior panels. The selected items used in the main test are listed in Table 2.

Table 2. Affects to evaluate exterior panels.

Affects	Question	Adjective
Hardness	When you press the panel with your hand, how hard is it to resist external force?	weak - hard
Deformation consistency	How the panel is consistently deformed when pressing the panel with your hand?	inconsistent - consistent
Thickness	How thick is the panel when pressing the panel with your hand?	thin - thick
Satisfaction	How satisfied are you when pressing the panel with your hand?	unsatisfied - satisfied

Evaluation questionnaire

The evaluation questionnaire used in this experiment consisted of four sections: questions for personal information; an explanation of the evaluation tasks and scenario; explanatory images of the three exterior panels; and rating scales of the four affects. The section on personal information included questions about the participants' ages, jobs, and driving experience. The task for evaluating panel stiffness was determined from the preliminary experiments, which involved pushing the panels with the palm of the dominated hand by the subjects. It was explained in the questionnaire that the subjects were to push the panels with all of their strength three to five times on a pre-marked point before rating the four affects. The evaluation scenario assumed that the participants would find the marked point, which seemed weak and unusual, while washing or reclining on a car, thus pushing on the point to assess the stiffness of the panel. The exterior panels to be evaluated were shown on a picture of a car in the questionnaire, and the pushing points were marked on the panels of the selected cars. The rating scale of the four affects used a seven-point semantic differential scale, all with positive values to prevent prejudgments, following Mondragón et al. (2005). An example of the rating scale is shown in Table 3.

Table 3. Example of evaluation question and scale.

When you press the panel with your hand, how hard is it to resist an external force?						
Very weak			**Neutral**			**Very hard**
3	2	1	0	1	2	3

Procedure

The procedures of the experiment are described in detail below. First, the participants were provided with explanations of the experiment's purpose and methods, and the participants signed informed consent documents. They were instructed with the given questionnaires about the detailed evaluation method, affects, and scenario. Each participant then physically approached the nine vehicles and evaluated the stiffness levels of the three panel parts in the prescribed, predetermined order. For the consistency of the experiment, each panel on all automobile was marked with spray paint so that the participants pressed the same position. The evaluation orders of the vehicles and the parts were randomized using a balanced Latin-square design to counterbalance any carryover effects. In the experiment, each vehicle was given a number, and five experimenters helped with any questions and difficulties on the part of the participants. After the experiment, which lasted an hour, the completeness of the evaluation questionnaire was assessed by the experimenters, and the subjects were compensated for their participation with fixed amounts of money.

Statistical analysis

The analysis of the results was conducted while assuming the rating score data as the interval. There have been many discussions regarding whether ordinal rating data can be statistically treated as an interval (Warnock et al., 2006). This study treated the semantic differential data as an interval and conducted a parametric analysis according to Rea and Parker (2005), who held that the power of information obtained greatly outweighs the cost associated with relaxing the technicalities in these scenarios.

Three types of analyses were conducted in the study. Analysis of variance (ANOVA) was performed to find significant factors related to the participants' affects, as well as a multiple-comparison test followed by a post-hoc analysis. A graphical analysis, which matched the panel curves with the level of the participants' satisfaction, was then conducted to connect the mechanical variables with the satisfaction levels. The relationship was then verified with an ordinary regression analysis by investigating the effects of the mechanical variables.

RESULTS

Significant factors influencing affects

Personal factors, such as age, job, and driving experience, had no significant effects on affects as they pertain to panel stiffness levels. To test the effect of each personal factor on the participants' affects, two-way ANOVA with a mixed-factor design was conducted in which the exterior panel was set as a within-subject factor, and each personal factor was a between-subject factor. The results for the hood are shown in Table 4 as an example. Regarding the affects related to the hood, rating scores for hardness showed no significant differences by age ($F(3,50) = 0.48$, $p = 0.69$). In addition, deformation consistency ($F(3,50) = 0.44$, $p = 0.72$), thickness ($F(3,50) = 0.84$, $p = 0.48$), and satisfaction ($F(3,50) = 0.06$, $p = 0.98$) showed identical results. There were also no significant interaction effects between age and the panels for hardness ($F(24,400) = 0.98$, $p = 0.49$), consistency ($F(24,400) = 0.94$, $p= 0.54$), thickness ($F(24,400) = 0.86$, $p = 0.66$), or satisfaction ($F(24,400) = 0.63$, $p = 0.91$). The remaining personal factors (job and driving experience) and their interactions with the panels also showed insignificant effects on all affects, with identical results for the front and rear doors.

In contrast, the exterior panels had a significant effect on the participants' affects. Excluding insignificant personal factors, one-way repeated-measures ANOVA was used to test the effects of the exterior panels on the affects (Table 5). Regarding the affects felt related to the hood, the scores for hardness showed significant differences depending on the panel ($F(8,423) = 19.61$, $p < 0.0001$). Additionally, deformation consistency ($F(8,423) = 19.00$, $p < 0.0001$), thickness ($F(8,423) = 10.46$, $p < 0.0001$), and satisfaction ($F(8,423)=19.68$, $p < 0.0001$) showed identical results, as did the front and rear doors. Therefore, hypothesis H_1 of this study, which stated that there are significant differences in customers' affects across varying exterior panels, was accepted.

Table 4. Summary of the personal factor effect on the effects of the hood.

Factor	Statistics	Hardness	Consistency	Thickness	Satisfaction
Age	*F(3,50)*	0.48	0.44	0.84	0.06
	p	0.69	0.72	0.48	0.98
Age × Panel	*F(24,400)*	0.98	0.94	0.86	0.63
	p	0.49	0.54	0.66	0.91
Job	*F(2,51)*	1.10	0.05	1.36	0.56
	p	0.34	0.95	0.27	0.57
Job × Panel	*F(16,408)*	1.30	1.35	0.70	1.10
	p	0.18	0.17	0.79	0.35
DE[a]	*F(3,50)*	2.80	0.91	2.01	0.78
	p	0.50	0.44	0.12	0.51
DE × Panel	*F(24,400)*	0.72	1.04	1.67	0.73
	p	0.84	0.42	0.05	0.82

[a] DE: Driving experience

Table 5. Summary of panel effect.

Panel	Statistics	Hardness	Consistency	Thickness	Satisfaction
Hood	*F(8,423)*	19.61	19.00	10.46	19.68
	p	<0.0001	<0.0001	<0.0001	<0.0001
Front Door	*F(8,423)*	8.48	6.88	7.51	6.44
	p	<0.0001	<0.0001	<0.0001	<0.0001
Rear Door	*F(8,423)*	8.47	10.05	10.80	8.87
	p	<0.0001	<0.0001	<0.0001	<0.0001

Graphical analysis of mechanical variable effects on customer satisfaction

The effects of the mechanical variables were basically investigated by matching the level of the affect score and the exterior panel curve. Among the four affects, satisfaction was used to analyze the effects of the variables because it is the overall affect and a key outcome of product/service usage (Bagozzi et al., 1999; Choe, 2013). In addition, the remaining three affects were scored very similarly to satisfaction in the evaluation experiment.

The mean satisfaction scores for the nine hoods are shown in descending order in Figure 3 and are statistically grouped with the SNK (Student-Newman-Keuls) test. The satisfaction level of hood 1 was highest at a significant level, followed by group B of hoods 2 to 5, C of 4 to 7, and D of 8 and 9, which showed the lowest satisfaction levels. Figure 4 shows the panel curves of the nine hoods with the panel number, as in Figure 3. Hood curve 1, with the highest satisfaction level, had the highest stiffness level, whereas hood curve 9, with the lowest satisfaction, had the lowest satisfaction level, with a large canning size. The two statistical groups of hood curves 2 to 5 and 4 to 7 could be classified into three types. Curves 2 and 3 had a low slope in the early phase of deflection, but the slope increased in the middle phase, and curves 4 and 5 had a high slope in the early phase, but both cases decreased in the middle phase. Curves 6 and 7 showed low slopes up to the middle phase but relatively high slopes in the later phases. In addition, hood 8, which had an overall slope similar to that of curve 7, showed a high slope in the early phase, which decreased up to the middle deflection phase. This result indicated that the satisfaction level associated with the hood increased as the slope of the panel curve increased, but it was negatively affected by canning and that the effects of the slope before and after the middle phase of deflection differed. Therefore, hypothesis H_2, which stated that customers prefer exterior panels with high stiffness levels, was accepted for the hood part. Moreover, hypothesis H_3 specifies that the slopes in the early and middle phases of the panel curve have different effects on satisfaction.

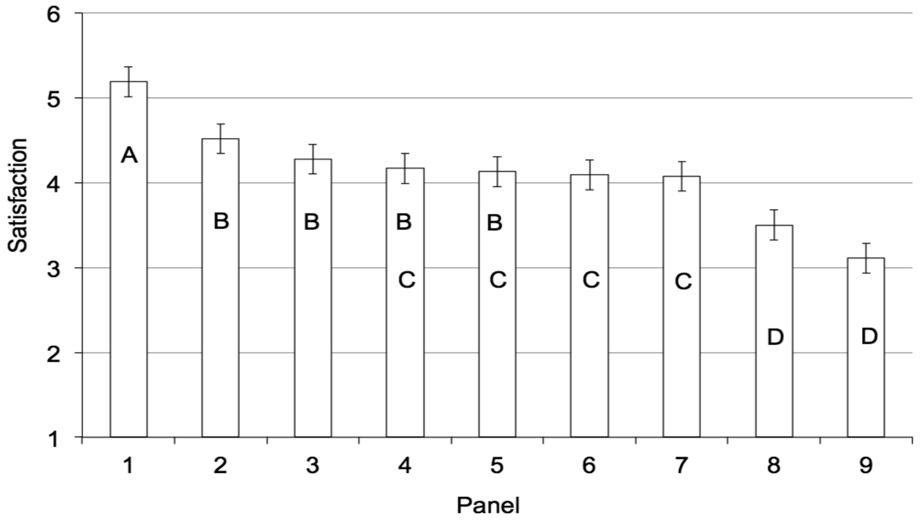

Fig. 3. Panel comparison regarding hood satisfaction (SNK group is denoted by letter).

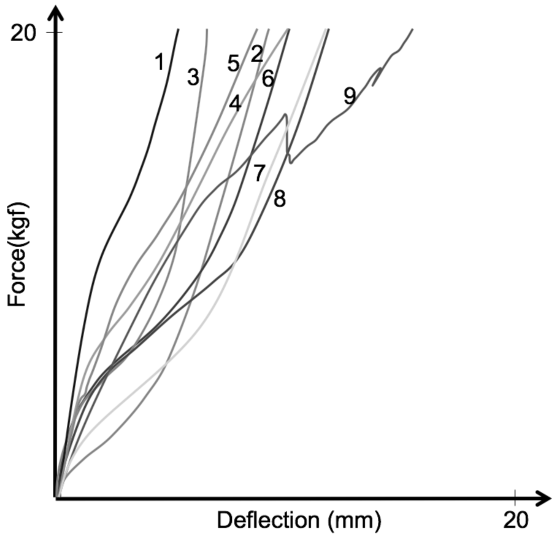

Fig. 4. Force-deflection curve of hood panels with hood number in Figure 3.

The mean satisfaction scores of the nine front doors are shown in descending order in Figure 5 and are statistically grouped according to the SNK test. The satisfaction level for front door 1 was highest at a significant level, followed by group B of front doors 2 to 7, C of 3 to 8, and D of 5 to 9, at the lowest satisfaction levels. Figure 6 shows the panel curves of the nine front doors with the panel number, as in Figure 5. Front door curve 1, with the highest satisfaction level, had the highest slope up to 14 kgf of force, but its slope decreased rapidly after that point and became the lowest throughout the entire range of deflection. This finding indicated that the participants evaluated the stiffness of the exterior panels with a force range of 0 to 14 kgf. At the point of 14 kgf, the slopes of curves 2 to 7, which were in group B, according to the SNK test, were similar to each other, while those of curves 8 and 9 were distinctly lower than those of the former cases. This distinction was unclear in the curve slopes of the entire range of deflection. Thus, hypothesis H5 holds that customers evaluate exterior panels with force up to 14 kgf. Although the panel curve of front door 7 had canning, its size was small, at less than 0.5 kgf, and it appeared to have no effects on satisfaction. This feature partially supported hypothesis H_4, which states that participants will not perceive a small degree of canning. Regarding the front doors, hypothesis H_2, which holds that customers prefer exterior panels with high levels of stiffness, was also accepted.

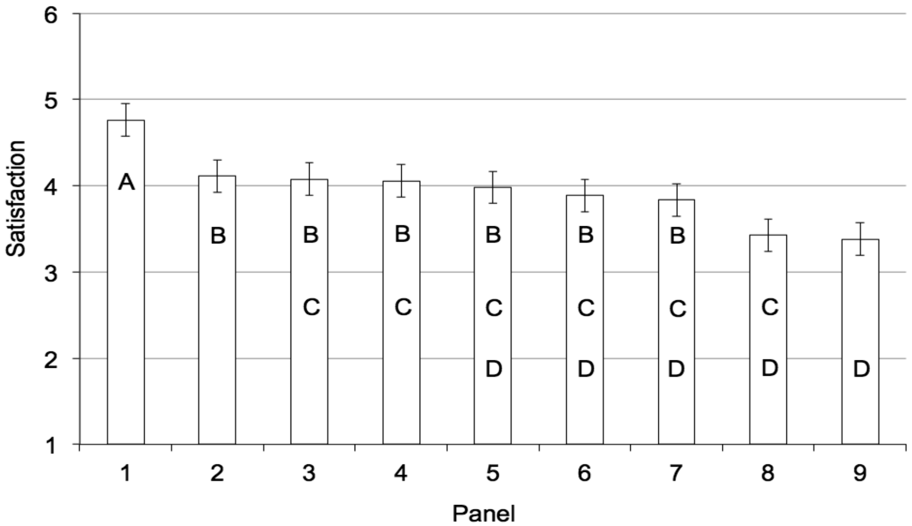

Fig. 5. Panel comparison regarding front door satisfaction (SNK group is denoted by letter).

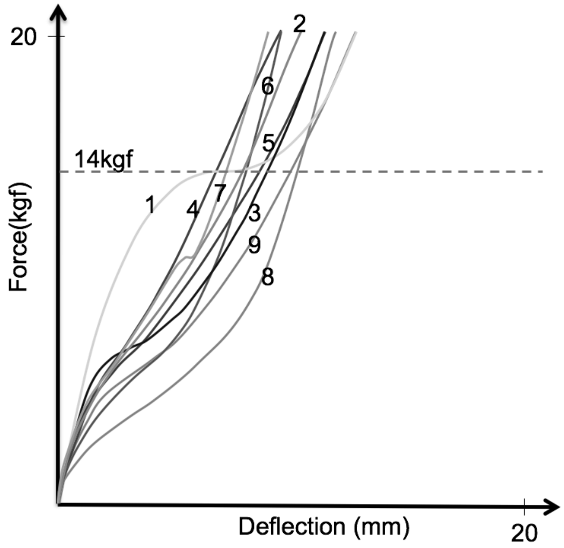

Fig. 6. Force-deflection graph of front door panels with the front door number in Figure 5.

The mean satisfaction scores of the nine panels of the rear doors are shown in descending order in Figure 7 and are statistically grouped according to the SNK test. The satisfaction levels of group A for panels 1 to 6 were significantly higher than those of group B for panels 7 to 9. Figure 8 shows the nine panel curves of the rear door with the panel number, as in Figure 7. Of panels 1 to 6 in group A with higher satisfaction levels, although panels 3 and 6 had large degrees of canning past a force level of 14 kgf, this fact appeared to have no effects on the evaluation. In addition, the slopes of curves 1 to 6 in group A up to 14 kgf were independently higher than those of curves 7 to 9. This finding also supported H_3, which holds that participants will evaluate the stiffness of exterior panels over a force range of 0 to 14 kgf. Hypothesis H_2, which states that customers prefer exterior panels with high stiffness levels, was also accepted for the rear door.

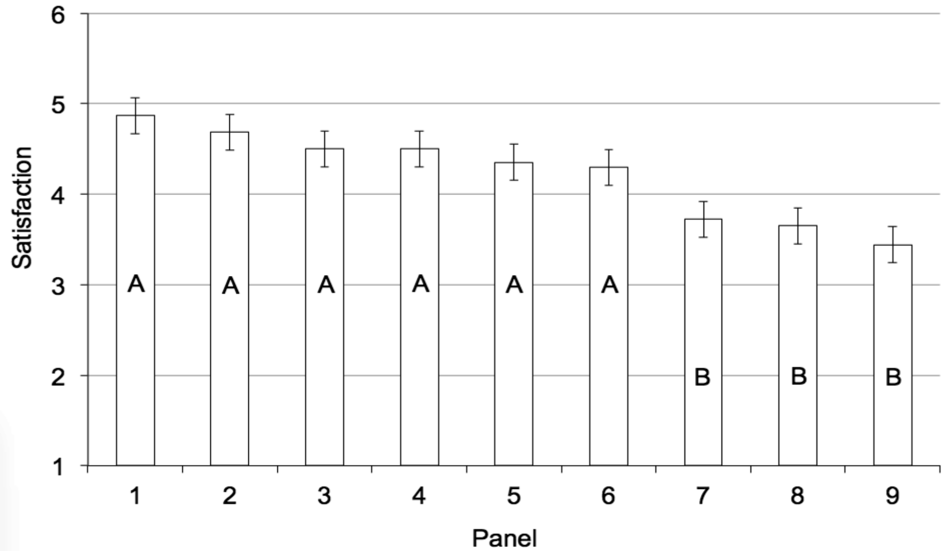

Fig. 7. Panel comparison regarding rear door satisfaction (SNK group is denoted by letter).

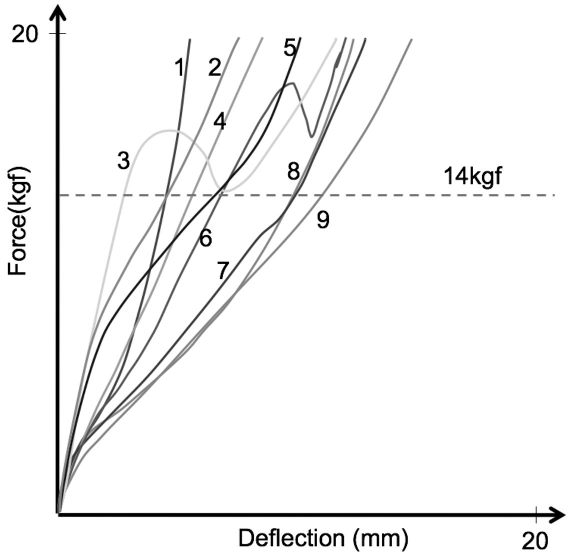

Fig. 8. Force-deflection graph of the front door panels with the rear door number in Figure 7.

Regression analysis of mechanical variable effects on customer satisfaction levels

Regression analysis was conducted to test hypotheses H_2, H_3, and H_5 and to identify the effects of the variables of the panel curves, which are related to the hypotheses. Hypothesis H_4 could not be statistically tested in the study because the number of canning cases was not sufficient. Hypotheses H_3 and H_5 as modified above are discussed below.

H_3: The slopes in the early and middle phases of the panel curves have different effects on satisfaction.

H_5: Customers evaluate exterior panels with a force range of 0 to 14 kgf.

To validate hypothesis H_5, regression models of satisfaction for the three parts were developed with the panel curve slope of 0 to 14 kgf as an independent variable, and they were compared to those with a slope of 0 to 20 kgf (the entire force range). To verify hypothesis H_3, regression models of satisfaction for the three parts were devised with two slopes of 0 to 7 kgf (the slope of the first half) and 7 to 14 kgf (the second half) as independent variables, and the models were compared to the other models. The coefficients of the two slopes were also compared.

The regression analysis (Table 6) found that H_3 and H_5 could be partially accepted depending on the exterior panel, while H_2 was fully accepted with a positive coefficient of the independent variables. For the hood, the regression model with the two slopes in the first and second halves of deflection had the highest adjusted coefficient of determination (adjusted R^2) of 0.70, and H_3 could thus be accepted. In this model, the effects of the first and second halves of the slope (the slope for 0-7 kgf and the slope for 7-14 kgf) on satisfaction accounted for 45% and 55% of the total, respectively, with their standardized coefficients. These findings showed that the effect of the second half of the slope on satisfaction was greater than that of the first half. In contrast, hypothesis H_5 was not accepted because the regression model with the slope of 0 - 14 kgf had a lower adjusted R^2 value (0.53) than the model with the slope of 0 - 20 kgf (0.67).

For the front door, H_5 could be accepted because the model with the slope of 0-14 kgf had the highest adjusted R^2 value (0.73). H_3 was also accepted due to a similarly high value of the adjusted R^2 (0.70) of the model with the two slopes of the first and second halves. For the rear door, both H_5 and H_3 were accepted because the model with the slope of 0 - 14 kgf showed the highest adjusted R^2 value (0.52), while the model with the two slopes of 0 - 7 and 7 - 14 kgf had slightly higher R^2 (0.48) values than the other case (0.46). In the regression analysis of all of the data for the three exterior panels, the models with the two slopes of 0 - 7 and 7 - 14 kgf (0.57) and with the slope of 0 - 14 kgf (0.55) had higher adjusted R^2 values than the other case (0.46), so both H_3 and H_5 could be accepted.

Table 6. RPE (rating of perceived exertion) and satisfaction regression model.

Panel	Predicted Variable	Adjusted R^2	Standardized Coefficient	t	p
Hood	Slope in 0-20 kgf	0.67	0.84	4.13	0.004
	Slope in 0-14 kgf	0.53	0.77	3.16	0.02
	Slope in 0-7 kgf	0.70	0.52	2.64	0.04
	Slope in 7-14 kgf		0.65	3.29	0.02
Front door	Slope in 0-20 kgf	0.05	-0.05	-0.14	0.89
	Slope in 0-14 kgf	0.73	0.87	4.71	0.002
	Slope in 0-7 kgf	0.70	0.88	4.49	0.004
	Slope in 7-14 kgf		-0.42	-2.17	0.84
Rear door	Slope in 0-20 kgf	0.46	0.73	2.84	0.03
	Slope in 0-14 kgf	0.52	0.76	3.10	0.02
	Slope in 0-7 kgf	0.48	0.43	1.41	0.21
	Slope in 7-14 kgf		0.46	1.52	0.18
Total	Slope in 0-20 kgf	0.41	0.66	4.42	<0.001
	Slope in 0-14 kgf	0.55	0.76	5.80	<0.001
	Slope in 0-7 kgf	0.57	0.59	4.38	<0.001
	Slope in 7-14 kgf		0.36	2.66	0.01

DISCUSSION AND CONCLUSION

This study identified that customers could differentiate varying levels of exterior panel stiffness and could evaluate their affects according to them. The analysis of the experimental data showed that the panels have significant effects on customers' affects for the hood, front door, and rear door, while the stiffness level of the panel curves was strongly correlated with these affects. This finding indicated that the participants perceived the stiffness level sufficiently by pushing on the panels with their hands and that they rated their affects based on this perception. Thus, H_1, which holds that the stiffness of exterior panels has an impact on customers' affects, was accepted. While Schutte and Eklund (2005) and Ayas et al. (2011) studied the force of controlling switches in relation to affective satisfaction, this study attempted to perform an affective evaluation of the external hardness of products and found that this approach is feasible.

The rating of affects did not differ significantly according to age, job, or driving experience in this study, indicating that the appraisal of the exterior panel stiffness is too simple and too reliant on the senses to be affected by personal experience. Norman (2004) classified affects into the three levels of visceral, behavioral, and reflective, and it is known that the last level is more likely to be influenced by personal experience, while the first is least likely. Other studies of visual satisfaction, such as those by Agost and Vergara (2014) and Seva and Helander (2009), have reported that personal factors were influential. However, the effects of the stiffness of panels appeared to be evaluated mainly based on the sensual dimension and to correspond to the primitive affects discussed in reference to the affect model of Kim et al. (2016). However, more studies of these types of affects are required to verify the effects of personal experience on them.

Although the effects of mechanical variables were analyzed only with regard to satisfaction in this study, the results would be similar for the other three affects. The Cronbach's alpha values of the four affects, measuring the internal consistency of the affects, were very high, at 0.92, 0.94, and 0.94 for the hood, front door, and rear door, respectively. This finding indicates that the four affects were evaluated in a similar manner and that they were strongly correlated with each other. Thus, it is expected that the effects of the variables on the hardness, deformation consistency, and thickness were similar to the effects on satisfaction levels. This study found that the three affects were correlated positively with the stiffness level of the panels and negatively correlated with canning, but the details were omitted due to space constraints.

This study estimated that male customers evaluated the stiffness of panels with a maximal force of up to 14 kgf on average. In the matching analysis of the satisfaction score and the panel curves, it appeared that the participants did not perceive a large degree of canning past a force of 14 kgf, nor did they reflect it in their evaluations. The regression model of satisfaction also showed higher explanation power of the data with the slope of 0 - 14 kgf than with that of 0 - 20 kgf. Snook (as cited in Sanders and McCormick, 1992) suggested that the maximum acceptable push weight for men was 15 kg with a task cycle of five minutes, similar to that in this study. Tanaka et al. (2011) found that the comfortable push force with one hand at elbow height was approximately 0.1 of the body weight, while the maximum push force was approximately 20 kgf. Thus, it is likely that the levels of applied force used to evaluate the panel stiffness by the participants were appropriate and were between comfortable and acceptable force levels. However, further study that directly measures the push force of subjects in a panel evaluation will be required to validate the estimated push limit of this study. If it is accepted, the affective design and quality control of panel stiffness levels will become easier due to the decreased testing load for exterior panels.

This study empirically confirmed the general idea that customers prefer exterior panels with higher stiffness levels and found that the slope of the middle phase is more influential than that in the early phase of the panel curve. By matching the satisfaction scores with the panel curves, it was affirmed that the rating scores of the panels were higher as the stiffness level of the panel curves increased, with the amount sufficient to explain the variance in the scores in the regression analysis. It appeared that the higher stiffness of the panels indicated that the subjects felt that the panel was hard, and this feeling induced an impression of a thick panel and satisfaction with its high quality. Especially in the panel curves of the hood, it was found that the stiffness in the middle phase was more influential than that in the earlier phase regarding satisfaction. This finding was confirmed with the regression coefficients of the models of the hood and the rear door, indicating that customers want exterior panels that, even when they can be deflected slightly with a small amount of force in the early phase, cannot be deflected additionally after the middle phase. However, more case studies are required to verify this finding because the same result was not found for the front doors.

This study assumed that canning has a negative effect on customers' affects, but this assumption could not be analyzed due to a lack of sufficient cases. The canning of exterior panels refers to an occurrence of sudden deflection without increasing the external force, and it is expected to have negative effects on customers' affects. Such a case was found for the hood, with the canning mostly occurring beyond a force amount of 14 kgf in the panel curves for the front and rear doors, with no negative effects. There was only one case of a small degree of canning with a force of less than 14 kgf, and it was not possible to conduct a quantitative analysis of the effects of canning in this study. The authors plan to study the effects of canning, including that on other panel parts and vehicles, in the future. If there are panels of similar stiffness levels with the only difference being canning, a sensitivity analysis of the degree of canning could also be possible.

This study used drivable vehicles in the experiment and could not completely exclude erroneous factors pertaining to certain brands in the panel evaluation. The tested vehicles were popular in the Korean market, and it was assumed that the participants recognized the brands and models given their common appearance in Korea despite their emblems being hidden in this study. Nonetheless, the evaluation of drivable vehicles was more suitable for this context. The subjects were instructed to evaluate their affects while focusing on the stiffness levels of the exterior panels to reduce the influence of the brand. Fortunately, the mechanical variables sufficiently explained the variance in the affects, and it could be inferred that the brand influence was not high.

The study obtained findings from only three parts of the exterior panels in mid-sized sedans and thus requires a test of external validity to determine whether the results could be applied to other parts of panels or other classes of vehicles. Further study is required in which a greater variety of parts of exterior panels, such as fenders, trunks, outer sides, and roof panels, as well as different classes of vehicles, are included. Finally, although this study adopted only four affects based on a literature survey and a pilot study, further work could construct a more complete semantic space of exterior panel stiffness levels using a greater variety of affective words with factor analysis.

In conclusion, this study aimed to investigate the effects of exterior panel stiffness levels on customers' affects, which has not been extensively studied in relation to automotive affective engineering. It was found that customers evaluate panels with a pushing force up to 14 kgf, that the slope of the panel curves had significant effects on their affects, and that their satisfaction increased as the slope increased. The authors believe that this study attempted to extend the realm of sensory modalities of affective engineering regarding the sense of force, showing the applicability of the approach.

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تحليل رضا العملاء عن صلابة اللوحة الخارجية للسيارات: التركيز على غطاء المحرك والأبواب لسيارة سيدان متوسطة الحجم

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الخلاصة

تُعتبر اللوحة الخارجية جزءً هاماً في السيارات ليس لأنها تُحدد المظهر التجميلي فحسب، بل لأنها تقاوم التأثيرات الخارجية أيضاً، كما تُعد صلابة الألواح الخارجية من بين عناصر المسح في دراسة الجودة الأولية (IQS) التي أجراها JD Power. تهدف هذه الدراسة إلى بحث آثار صلابة الألواح الخارجية على مستويات رضا العملاء لأن هذه العلاقة لم تُدرس على نطاق واسع في مجال هندسة السيارات. تم اختيار أربعة تأثيرات لهذا التقييم لمستويات الصلابة الخارجية للوحة: الصلابة، الاتساق، السماكة، ومستويات الرضا المرتبطة بها. في هذه التجربة، قام 54 رجلاً كورياً تتراوح أعمارهم ما بين 20 و 50 عاماً بتقييم ثلاثة أجزاء من الألواح الخارجية على تسعة سيارات سيدان متوسطة الحجم. وشملت هذه الأجزاء غطاء المحرك والباب الأمامي والباب الخلفي. وأظهرت النتائج أن مستويات رضا العملاء تختلف اختلافاً كبيراً اعتماداً على اللوحات، وقد زادت درجة الرضا عندما كانت الصلابة أكبر. كما قام المشاركون بتقييم مستويات صلابة الألواح بقوة تصل إلى 14 كجم. تم تطوير نماذج رضا العملاء مع المتغيرات التي تم العثور عليها لوصف الخواص الميكانيكية للألواح. وستكون هذه النماذج مفيدة للأشخاص المشاركين في تصميم والتحكم في جودة الصلابة للألواح الخارجية.