공학석사학위논문

도어트림 오염을 최소화하기위한 자동차 설계방안과 승/하차 동작 분석

Vehicle Design Method and Ingress/Egress Motion Analysis to Minimize Door Trim Scuff and Soil

2018 년 2 월

서울대학교 대학원

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이 논문을 공학석사 학위논문으로 제출함

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최은수의 공학석사 학위논문을 인준함

2017 년 12 월

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Abstract

Human factors design is becoming increasingly important in the automobile industry. However, if the interior materials of a car are not maintained, human sensibility is affected. Although the maintenance of the interior materials of vehicles is a chronic problem according to J.D. Power, existing solutions have been limited to surface treatment and materials. Thus, to prevent scuff and soil, an ergonomic solution using human ingress/egress motion is proposed. Specifically, automotive design parameters were studied to determine their influence on maintenance defined as contact with the pressure pad located on the front door trim. In this research, door trim is a major concern. Ingress/egress experiments were performed 3 times with a customized and parameterized vehicle mock-up, validated as similar environment as a real automobile by an inertial motion capture device. A 6-parameter experiment was conducted at first and each one parameter was screened for each experiment by half normal probability plot. As a result, 4 vehicle parameters plus vehicle types were analyzed by ANOVA. Each experiment was based on the design of experiments. Low and high levels of parameters were determined within a range of mock-up covers but were sufficiently apart. Three parameters were selected as the most influential factors: A-pillar to H-point, H-point to sill, and Door open angle. Other minor parameters were rejected: H-point to ground, Sill height, and Door trim extrusion. An optical motion capture was performed in 3rd experiment. With motion capture data, informative joints to classify motion that made scuff and soil, were selected by recursive feature elimination. K-nearest neighbors algorithm was used as classification. Hip, knee, and subtalar were selected as the most influential joints to scuff and soil. Therefore, parameters and motion analysis would make vehicle designers understand ingress/egress motion causing interior scuff and soil and introduce vehicle design method to solve the problem.

Key words: Vehicle ingress and egress motion, Vehicle door trim, Scuff and soil, Motion analysis.

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1. Introduction

As automobile performance is highly standardized, consumers value comfort and pleasure as a living space beyond the efficiency of mobility. Therefore, automakers are considering factors such as internal space utilization, in-vehicle infotainment, human interaction, and ergonomics as well as existing indicators of automobile performance such as fuel consumption, R&H, NVH, and safety. Among these changes, convenience and comfort in space are connected to design from an ergonomic point of view. Thus, ergonomic automotive design is one way to differentiate products and improve product competitiveness.

There are various emotional factors in the interior of the car. It can include all interactions between people and cars, such as the driver's visual, auditory, cognitive, tactile, and gestural. Hence, there are many ergonomic design elements inside the car. The automotive interior noise analysis for hearing [1], the improved grip of the hand design for sense of touch [2], interaction between vehicle and the driver for cognition [3], and discomfort analysis during ingress/egress for ergonomics [4] are conducted. Despite numerous attempts at automotive interior design, there are few studies of the visual comfort of interior space. *Kansei engineering. Here, visual comfort. Therefore, if the interior of automobile is dirty, it will greatly reduce its visual comfort. In fact, according to "Initial Quality Study: Top Reported Problems" of J.D. Power, which is the world leading authority in consumer satisfaction surveys in the automotive sector, interior materials that scuff and soil easily is on the rise for two consecutive years in 2014 and 2015 [5,6].

Interior scuff and soil are mainly caused by human. People frequently scratch and stain internal materials such as door trim, door scuff, and bottle holder during ingress and egress. Although it is rare to study these scuff and soil, there are researches that approach interior parts in a material way. It is a method to use materials that are difficult to be scuffed and soiled. However, this material aspect is only a temporary measure. Contrast to material studies, in this study, I approached the point of human motion view and recognized that the human foot touches the automobile interior material as a fundamental problem. Therefore, the goal of research is to reduce the contact between the foot and the interior material during ingress and egress by ergonomic automobile design and to understand ingress/egress motion.

Vehicle ingress and egress motion research has been mainly conducted on discomfort. Kim and Lee used muscle forces, unlike the conventional use of joint angles, to evaluate the discomfort of ingress [4]. The evaluation method is developed by the mathematical correlation between muscle forces and discomfort obtained by fuzzy logic. To calculate muscle forces, optical motion capture of the ingress motion was performed on vehicle mock-up. Choi and Lee focused on trucks to evaluate the discomfort of ingress and egress [9]. Optical motion capture was used under various truck mock-up conditions. Based on the captured data, maximum voluntary contraction ratios of the muscles were calculated to evaluate the discomfort of the motion. There is also study that estimates the discomfort. Hadi I. Masoud, et al. proposed a modeling framework using human motion curves to predict subjectively reported discomfort during ingress [10]. A classification and prediction model is built using a support vector machine after important joint trajectories are filtered and identified. The results are more accurate than a model using anthropometry and vehicle design variables as inputs.

Studies on the analysis of the form of vehicle ingress and egress motion have been conducted. MOA El Menceur, et al. presents the ingress and egress movement strategies adopted by 41 young and elderly subjects with or without prostheses [11]. Four different types of stripped vehicles are used in the experiments. Five ingress and three egress movement strategies are identified. Chateauroux and Xuguang categorizes car egress motion by younger and older participants [12]. Motions of 7 young and 18 old volunteers are captured on four different types of car. As a result, two main car egress strategies are observed. Lu, Jun-Ming, et al. investigates the motion strategies of young and elderly passengers while entering and exiting the rear seat of minivans with sliding doors [13]. 10 young and 10 elderly male participants entered and exited the minivan mock-up while acquiring motion data. Finally, all motions are categorized into seven ingress and seven egress motion strategies. Even though there are several types of ingress and egress motion, most studies conclude that dominant mode of the motion exists. Thus, people's ingress and egress motion of the vehicle is not significantly different.

In ingress and egress motion research, vehicle mock-ups have been considered essential equipment. MOA El Menceur, et al. used the four stripped vehicles; small utility, minivan, medium car and small car [11]. Chateauroux and Wang also used small cars, medium cars, small commercial vehicles and minivans [12]. However, there is a difference in size among automobile makers even with the same type. Hence, in order to represent one type, a certain degree of change should be given to the mock-up. To solve this problem, there are studies that have made mock-up adjustable. Kim and Lee made the adjustable vehicle mock-up to analyze the ingress motion, but only three parameters were changeable; the height of the side panel, and width and the position of the A-pillar [4]. Causee, et al. made mock-up to adjust seven parameters [14]. However, in this case, the number of changeable parameters seems to be small to reflect a particular type of vehicle. Therefore, in this paper, I designed and made a multi-dimensional adjustable vehicle mock-up that provides a variety of automobile environments.

In this study, main vehicle parameters, affecting scuff and soil of interior materials, are selected and their relative impacts are analyzed. Many studies have been carried out to consider various parameters of the vehicle and to select significant ones. In particular, such research has been conducted in a vehicle crashworthiness. Craig, et al. introduced a factor screening method based on response surface methodology and analysis of variance in automotive crashworthiness design [15]. Shujuan Hou, et al. screened vehicle body parameters using crash FEM simulation and unreplicated saturated factorial design method to find major factors of multivariable crashworthiness optimization [16]. In this paper, similarly, main parameters for scuff and soil of vehicle interior materials are selected through design of experiments. Furthermore, there are studies that focus on analyzing the impact of design parameters. M. Santhakumar, et al. used Pareto-ANOVA to analyze the sensitivity of hydrodynamic parameters of flatfish type autonomous underwater vehicle [17]. In areas other than vehicle, Mousavi and Parvini used ANOVA to find environment factors and processing parameters that affect hydrogen release and dispersion [18]. Thus, ANOVA has been widely used in analyzing the influence of parameters. This paper also uses ANOVA to analyze the significance of the selected parameters.

In this paper, ingress/egress motion is analyzed to prevent scuff and soil of vehicle interior materials, which are frequently happened in reality. Scuff and soil are mostly caused by contact between human foot and interior materials. Therefore, an adjustable mock-up reflecting vehicle parameters is made. Ingress/Egress motion is captured the degree of scuff and soil due to ingress/egress is obtained as mock-up parameters are changed. Scuff and soil are measured by a pressure pad attached to the door trim. Through three times ingress/egress experiments, main vehicle parameters that significantly affect scuff and soil are selected and finally, theirs impacts are quantitatively calculated. These results and analyses will provide design directions to minimize interior materials scuff and soil in the automotive industry. The detailed research method is as follows.

2. Method

2.1 Vehicle mock-up

2.1.1 Design

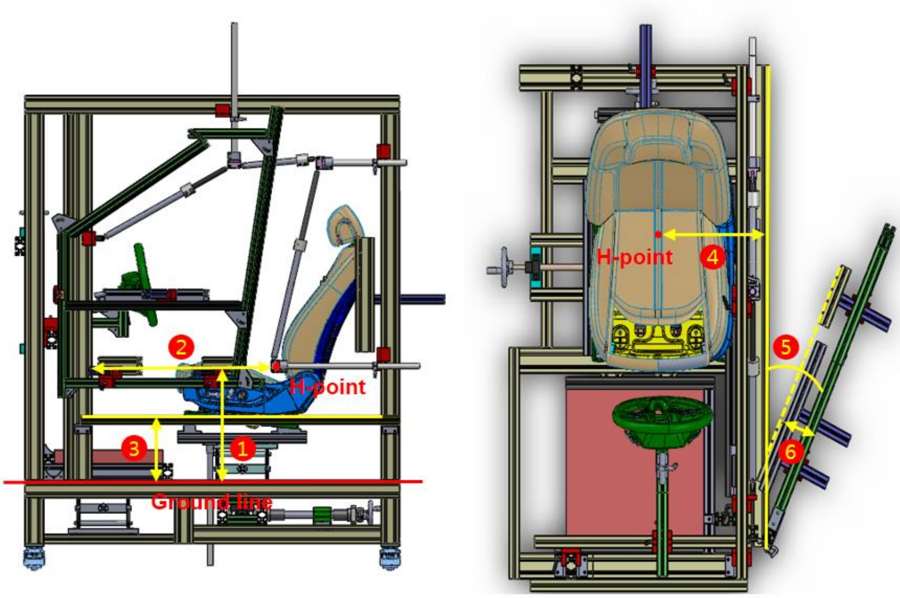


Fig. 1 Vehicle mock-up parameters

No.	Definition	SAE
1	H-point to ground	H5-1
2	A-pillar to H-point	–
3	Sill height	H130-1
4	H-point to sill	W5-1
5	Door open angle	–
6	Door trim extrusion	–

Table. 1 List of vehicle mock-up parameters

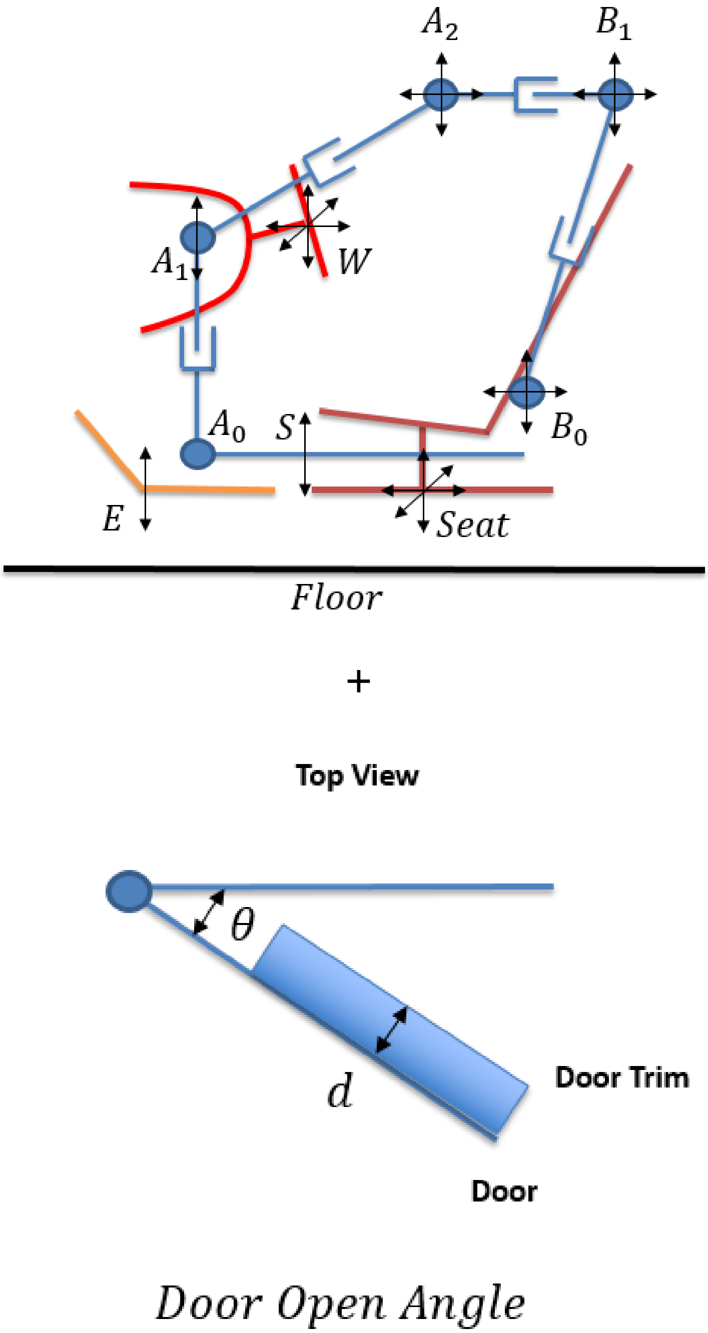


Fig. 2 Degree of freedom of mock-up

For the experiment and analysis of ingress/egress motion varying vehicle environment, the multi-dimensional adjustable vehicle mock-up is made. The parameters of mock-up that can have significant effects on ingress/egress and scuff and soil of interior materials are shown in Fig. 1. Among the interior materials, I concentrate on the door trim where scuff and soil are most easily caused by the foot. The four vehicle package layout parameters, door open angle, and door trim extrusion, which can affect the lower body motion, are assumed to be the most important design variables. In practice, these are parameters that can be reflected in the design. The chosen parameters are H-point to ground, A-pillar to H-point, Sill height, H-point to sill, Door open angle, and Door trim extrusion in Table. 1. For convenience, parameters are abbreviated to HtG, AtH, SH, HtS, DOA, and DTE respectively. Similiar definitions of SAE J1100 (2009) are matched. In addition to these six parameters, the shape of the vehicle entrance affects the ingress/egress motion, too. Thus, A-pillar and B-pillar, which determine the entrance shape, are constructed as variable links and adjustable. All manipulation parts are made for manual operation and adjustable in mm with attached scale. The schematic diagram of the degree of freedom of designed mock-up is shown in Fig. 2. During experiment, the ingress/egress motion data is obtained by optical motion capture system (12 cameras, MX-T160, Vicon, Oxford, UK). Hence, the mock-up is configured of an anti-reflection aluminum frame to ensure optical cameras' field of view and minimize effects of noise.

2.1.2 Validation

Fig. 3 Ingress/Egress experiment with inertial motion capture device

Much ingress/egress research have used the mock-up. However, no research have proven that the mock-up provides the same environment as a real car. If the cross-validation between the actual vehicle and the mock-up is not performed, the reliability of the experimental equipment will be reduced. Moreover, even if the mock-up does not provide minimal similar environment, it is out of the essence of ingress/egress research. Therefore, in this research, the validity of the experimental equipment is verified by comparison analysis of human motion in real vehicle and mock-up adjusted to the same condition(Fig. 3). The vehicle used is LF Sonata (Hyundai, Seoul, Korea) and inertial motion capture device used is MVN (Xsens, Enschede, Netherlands). MVN is a wearable 3D motion tracking device based on IMU and can calculate each joint angle. Since it does not need a camera like optical motion capture system, it is suitable for an environment that obstructs the camera view like an actual car. One male subject (age 25 years, height 175 cm) is recruited.

2.2 Scuff and soil

2.2.1 Definition

Interior scuff and soil are literally divided into two cases. One is when the interior material is permanently scratched, and the other is when the interior material gets dirty. The former case can be judged as the magnitude of contact because it occurs when the interior material is strongly crashed by the human foot. In the latter case, the degree of soil increases as the interference between the interior material and the human foot occurs widely, so it can be defined by the area of contact. Therefore, interior scuff and soil are defined by magnitude and area of contact.

2.2.2 Measurement

Pliance (novel GmbH, Munich, Germany) is used to measure the vehicle interior scuff and soil during ingress and egress. Pliance is the pressure pad composed of 1024 small cells (32 horizontal and 32 vertical) like Fig. 4, so that the magnitude and area of interference between the interior and the human foot can be measured in detail. Fig. 4 is an example that the interior is physically interfered by the human foot. Pliance is attached to the front part of the lower edge of the door trim where the interference is most occurred because the gap between the pressure pad and the foot is the smallest.

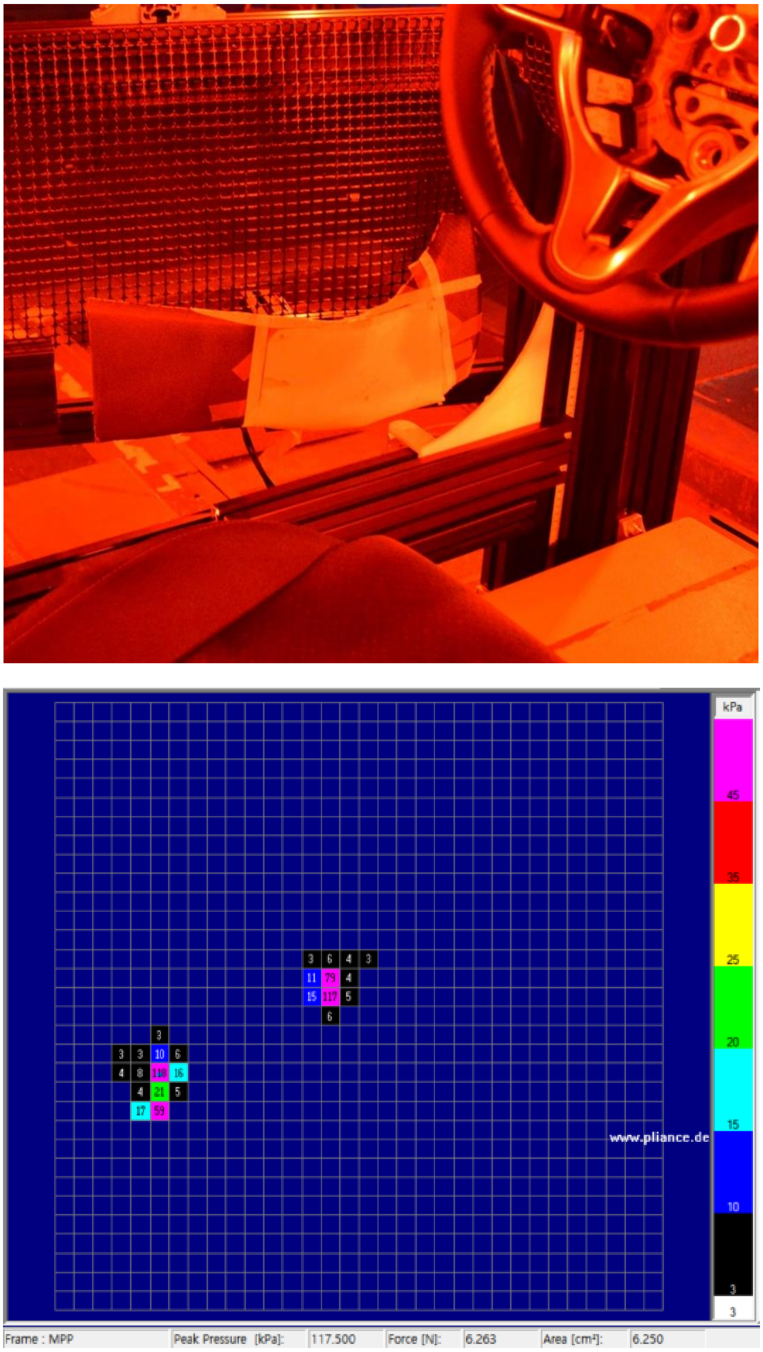


Fig. 4 (Up) Pliance attached to door trim, (Down) Pliance software

2.3 Ingress/Egress experiment

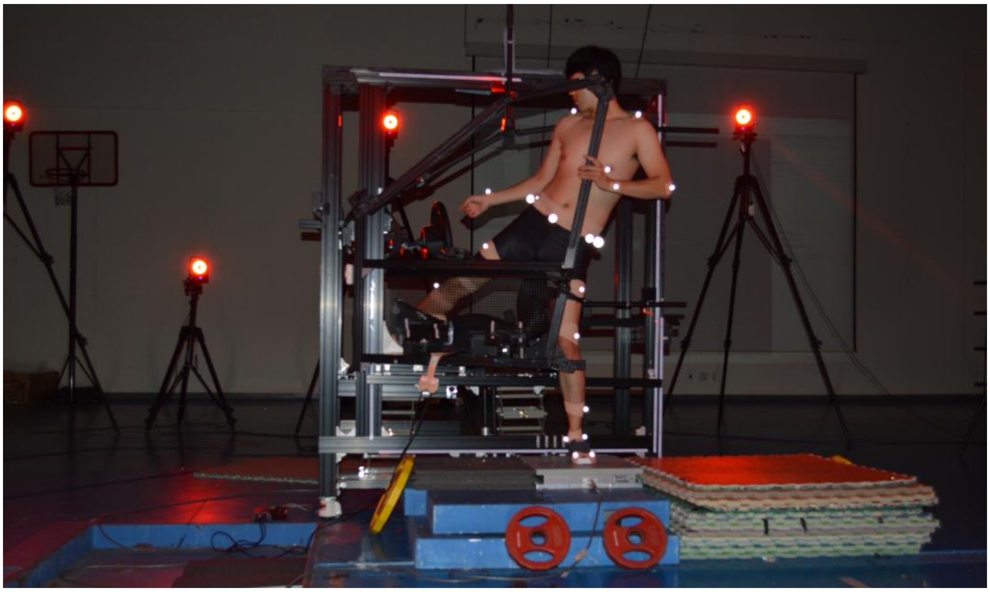


Fig. 5 Ingress/Egress experiment with optical motion capture system

Ingress/Egress experiment enables the measurement of scuff and soil and the acquisition of motion data. The adjustable vehicle mock-up, optical motion capture system (12 cameras, MX-T160, Vicon, Oxford, UK), optical markers, force plate (AMTI, Boston, MA, USA), pliance are used during experiment. Subjects perform ingress/egress each given condition of experiment. They are given enough practice before experiment for natural acts. In the 3^{rd} experiment, motion capture is performed. Subjects of 3^{rd} experiment attach reflective infrared markers to their body based on Plug-in Gait Marker set and carry out ingress/egress experiment. The main vehicle parameters of scuff and soil are selected among six chosen parameters. Factor screening is conducted twice using half normal probability plot and the influence of selected parameters is analyzed by ANOVA.

2.3.1 Design of experiments

Design of experiments is introduced to conduct ingress/egress experiment systematically. 1st and 2nd experiments are the factor screening processes so they are planned by 2-level full factorial design [19]. This is because the 2-level full factorial design is suitable for early stage applicants when many parameters need to be considered. It is often used in the factor screening process because fewer experiments show the influence of the parameters. In order not to erroneously analyze the influence of the parameters, the largest difference between the low (-1) and the high (+1) levels are set-up in realistic range. 3rd experiment is conducted based on the central composite design to investigate parameters in more details [20]. The central composite design is an extension of the 2-level full factorial design by adding center points and axial points at the factorial cub point to analyze the curvature of the response values. The distance from the center point to the axial point, α, together with the number of center points, can determine whether the design of experiments is orthogonally blocked and rotatable. For rotatability, α is determined by $\alpha = (2^k)^{1/4}$.

2.3.2 Experiment

2.3.2.1 1st Experiment

* Unit: 1, 2, 3, 4, 6: mm, 5: degree

No.	Definition	Level	
		-1	+1
1	H-point to ground	470	630
2	A-pillar to H-point	720	820
3	Sill height	270	470
4	H-point to sill	300	400
5	Door open angle	34	50
6	Door trim extrusion	180	200

Table. 2 1st experiment factorial design

In the 1st experiment, a male subject (age 30 years, height 174 cm) is recruited. Using 2-level full factorial design, two levels per parameter are shown in the Table. 2. Each parameter size is applied by Hyundai sedan vehicles; Verna, Avante, Sonata, and Genesis. The largest dimension is adopted as +1 level and the smallest dimension is adopted as -1 level. In the case of DOA parameter, the -1 level is set to the first checker angle and the +1 level to the second checker angle. The checker angle refers to a step angle at which the door is locked when the door is opened without a certain amount of force. Because the experiment is planned by six parameters of 2-level full factorial design, $2^6 = 64$ times of ingress/egress have to be conducted. However, in the early stage of the experiment, there is no sign of interference between the door trim and foot at +1 level of DOA. Hence, except DOA, 32 times of ingress/egress are performed.

2.3.2.2 2nd Experiment

* Unit: 2, 3, 4, 6: mm, 5: degree

No.	Definition	Level	
		-1	**+1**
2	A-pillar to H-point	700	800
3	Sill height	330	410
4	H-point to sill	460	560
5	Door open angle	28	34
6	Door trim extrusion	190	230

Table. 3 2nd experiment factorial design

In the 2nd experiment, two male subjects (age 30, 32 years, height 174, 180 cm) are recruited. Using 2-level full factorial design, two levels per parameter are shown in the Table. 3. Each parameter sets -10% of the dimensions to -1 level and +10% to +1 level based on Hyundai's most popular mid-sized sedan, Sonata. In the case of DOA parameter, -1 level sets $28°$, less than the first checker angle. This is because, in the first experiment, interference between the door trim and the foot occurs in a narrow environment where the DOA is smaller than the first checker angle. As a result of the first experiment, HtG is excluded, so five parameters of 2-level full factorial design and two replicates make $2^5 \times 2 = 64$ times of ingress/egress.

2.3.2.3 3rd Experiment

* Unit: 2, 4, 6: mm, 5: degree

No.	Definition	Level									
		Sedan					SUV				
		-2	-1	0	1	2	-2	-1	0	1	2
2	A-pillar to H-point	680	720	760	800	840	610	650	690	730	770
4	H-point to sill	450	480	510	540	570	410	430	450	470	490
5	Door open angle	28	30	32	34	36	28	30	32	34	36
6	Door trim extrusion	190	200	210	220	230	130	137.5	145	152.5	160

Table. 4 3rd experiment central composite design

3rd experiment is based on the central composite design to analyze the influence of selected parameters in detail. Because $\alpha = (2^k)^{1/4}$, $\alpha = 4$. In order to increase the robustness of results, 10 male subjects (age 25.5 $\pm$ 5 years, height 180 $\pm$ 5 cm) are recruited. Using central composite design, five levels per parameter are shown in the Table. 4. In addition to sedan, SUV model is considered because those are representatives of a large range of the automobile types presently on the market. Likewise the 2nd experiment, parameters of sedan set -10% of the dimension to -1 level and +10% to +1 level based on Hyundai Sonata. Similarly, parameters of SUV set -10% of the dimension to -1 level and +10% to +1 level based on Hyundai's mid-sized SUV, SantaFe. As a result of the 2nd experiment, SH is excluded, so four parameters and vehicle types of central composite design and two replicates make 124 times of ingress/egress for each subject. In addition, all the parameters (20 degrees of freedom) that can be change in the vehicle mock-up have been adjusted referring to Sonata and SantaFe, creating an environment very similar to the actual vehicle.

2.4 Motion analysis

Ingress/Egress motion, causing scuff and soil of the door trim, is analyzed. This is to find out why the door trim scuff and soil is occurring as well as vehicle parameters analysis. In the 3rd experiment, ingress/egress motion is captured and ingress/egress motion data is converted to human joint angles by inverse kinematics. In sequence, it is found out which movement of the joint is most important for the door trim scuff and soil by the recursive feature elimination.

2.4.1 Data processing

Motion capture data is obtained by infrared cameras, tracking optical markers. The obtained marker data is manually labeled using Nexus (Software, Vicon, Oxford, UK) and C3D data is extracted using Mokka (Biomechanical Toolkit, Lausanne, Switzerland). Then, subject-specific skeletal models are created using OpenSim 3.3 [21] and Hamner Full Body Model [22]. Finally, inverse kinematics is performed to calculate joint angles. In addition, inverse kinematics is based on the weighted least squares equation.

2.4.2 Recursive feature elimination

Recursive feature elimination is applied to identify major joints in door trim scuff and soil. It is one of methods of feature selection using classification machine learning. After training data are used to learn with the chosen machine learning algorithm, cross-validation is used to rank the features in order of affecting the classification accuracy. Then, the least influential feature is excluded and same procedure is repeated until all features are removed. As a result, the ranking of impacts on the classification of all features will be obtained. In this research, the motion that causes the door trim scuff and soil as 1 and the motion that does not cause as 0 as the output of classification. Features are defined as 37 human joint movements that can be represented by human motion. The algorithm for learning data in recursive feature elimination uses KNN (K-Nearest Neighbor) algorithm. Applying all the classification algorithms provided by MATLAB R2017a, KNN algorithm is the best fit for motion data. Moreover, because effects of each feature may be sometimes similar, 700 times of recursive feature eliminations are repeated to improve the robustness of the results.

3. Result

3.1 Mock-up validation

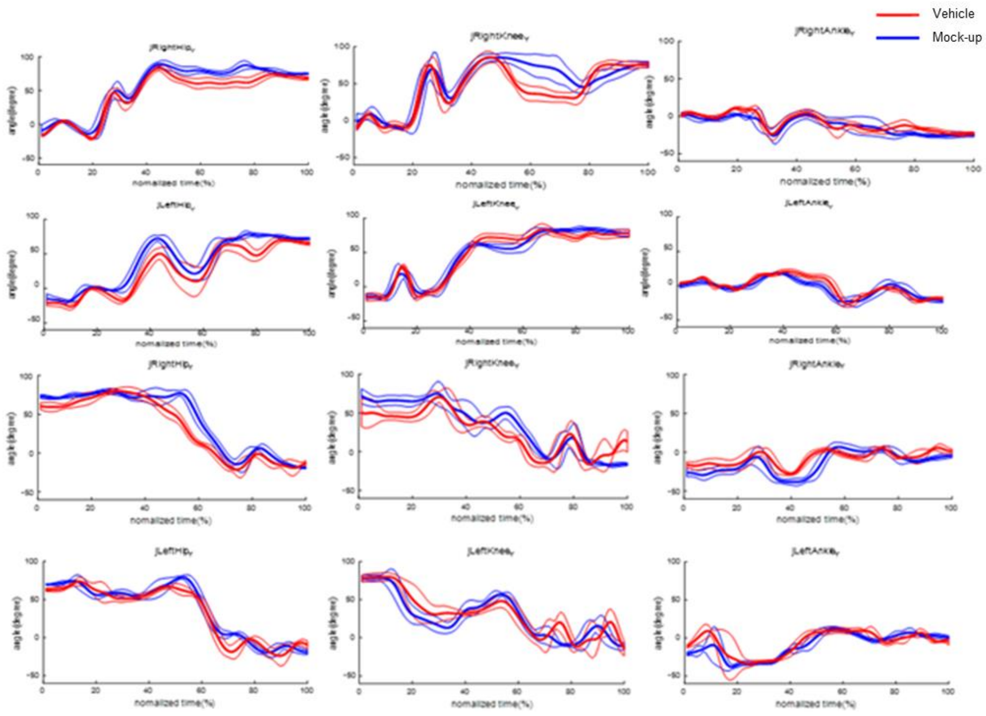
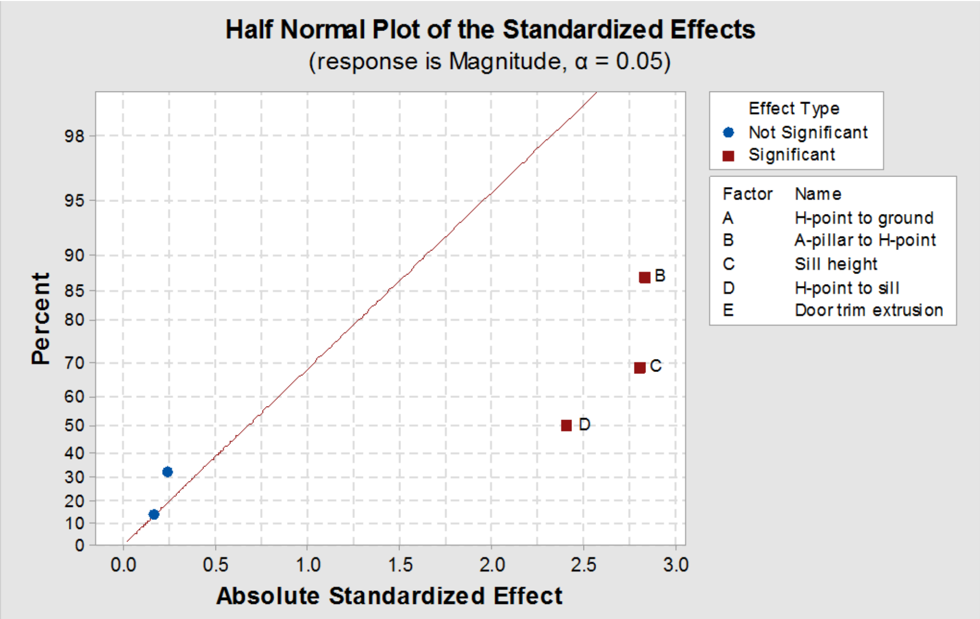


Fig. 6 Ingress/Egress joints (hip, knee, ankle) angle of actual vehicle and mock-up

To verify whether the actual vehicle and the mock-up provide the same environment, the variation of major joint angles is compared and the similarity is examined. Fig. 6 is a graph comparing the variation of six major joints (left and right hip, knee, and ankle) in time series extracted from a number of ingress/egress operations. The red line is the ingress/egress motion at the actual vehicle and the blue line is at the mock-up. They are expressed by a 1-sigma interval plot composed of standard deviation and mean. As described in Fig. 6, the time series variation in major joints is very similar in the ingress/egress. Especially, the similarity is conspicuous in a section where interference between the door trim and the foot can occur. Therefore, the mock-up designed and manufactured in this study provides the ingress/egress environment comparable to the actual vehicle.

3.2 Factor screening



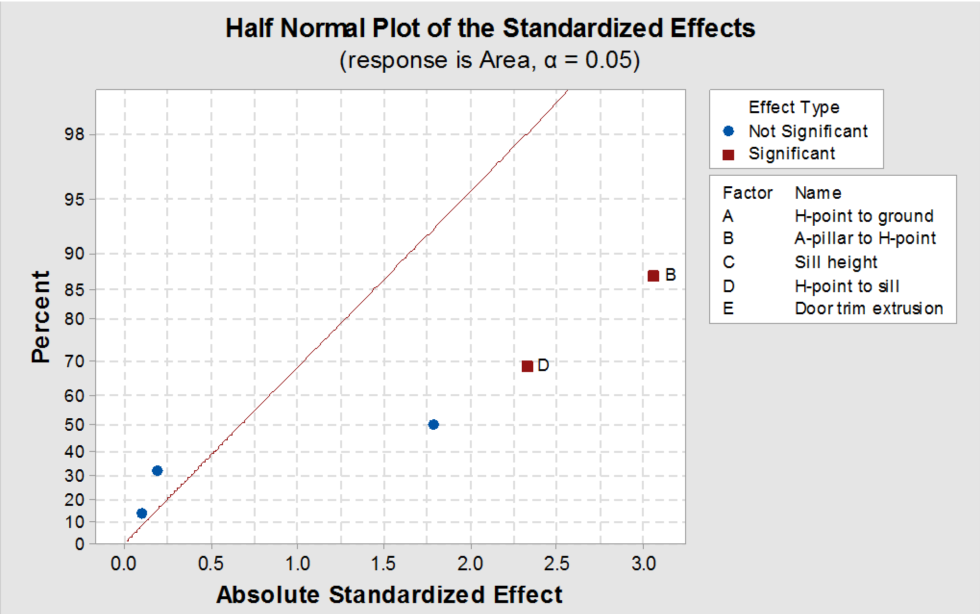


Fig. 7 1st experiment half normal probability plot (Up) Magnitude, (Down) Area

Half normal probability plot is used to compare the difference of relative effects among parameters. It compares the magnitude of the main effect and the interaction effect in 2-level factorial design and confirms the statistical significance. In this procedure, the main effect is only investigated because key parameters need to be selected. Half normal probability plot is suitable to compare the relative magnitude among parameters because it displays the effect with an absolute value. In this study, the statistical significance level is $\alpha = 0.05$, and the results of the magnitude and area of the pressure, which is the definition of scuff and soil, are analyzed separately. In the 1st experiment, five parameters are examined except DOA. As shown in Fig. 7, AtH, SH, and HtS are overwhelmingly influential compared to HtG and DTE. However, it is judged that the influence of DTE is relatively small because the interval between low and high levels is not enough compared with that of other parameters. Therefore, in the next experiment, DTE is considered again while HtG with little influence is excluded.

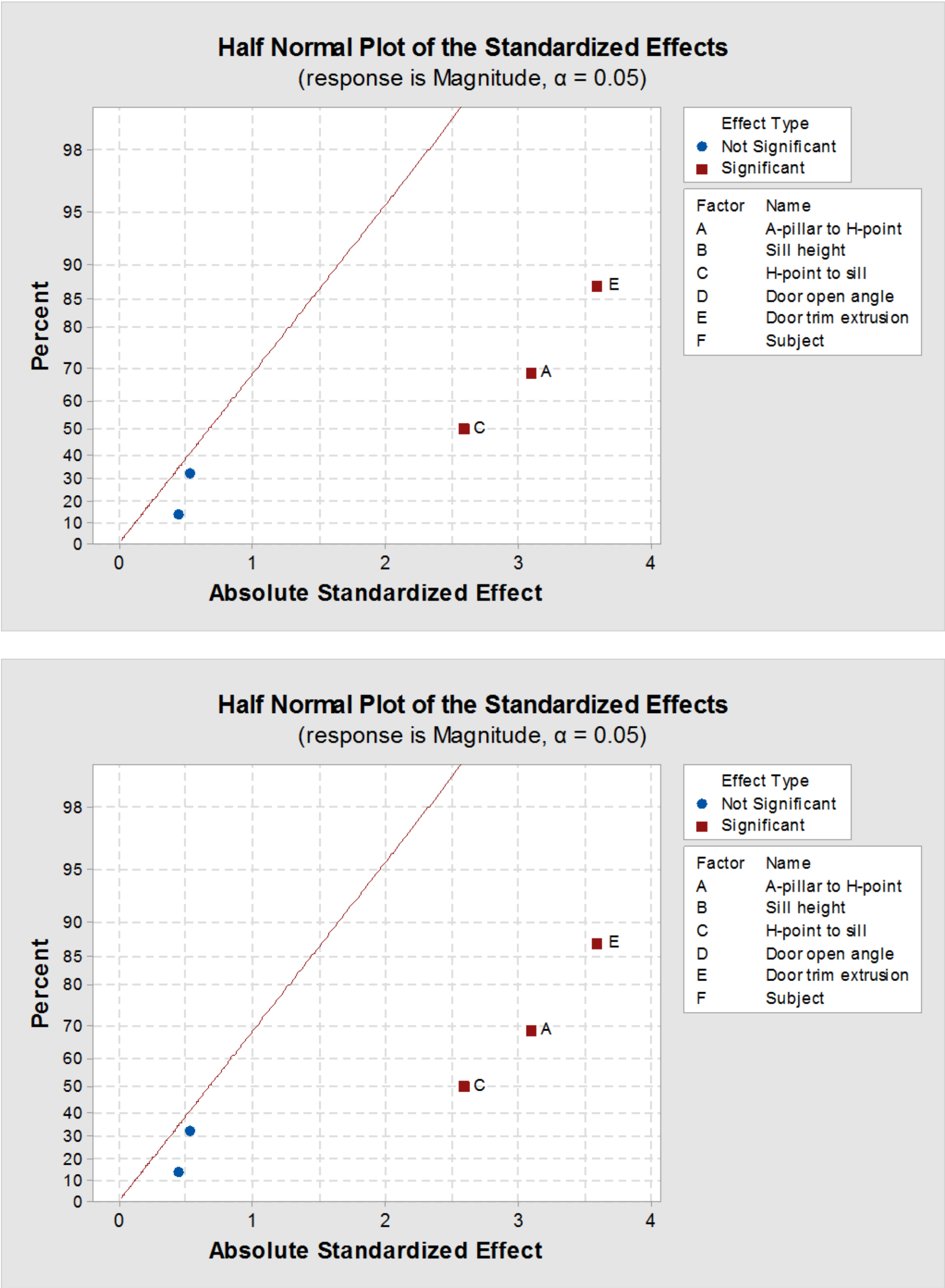


Fig. 8 2nd experiment half normal probability plot (Up) Magnitude, (Down) Area

In 2nd experiment, DOA that is excluded in the 1st experiment is included because I decide to look at a smaller angle than the first checker angle. In a narrow environment such as a parking lot, it is difficult to open the vehicle door even by the first checker angle. Thus, five parameters are analyzed. As a result, Fig. 8 shows that AtH, HtS, and DTE have more influence than SH and DOA. Although DOA's impact was low, it is included again in the next experiment to maintain a narrow environment such as a parking lot where scuff and soil occurs frequently. Also, there will be an interaction effect between the door trim and DOA because DOA is dependent on the door. Consequently, the 3rd experiment is carried out except SH.

3.3 Parameter analysis

3.3.1 Analysis of variance

ANOVA is used to obtain the significance of each parameter. Table. 5 and 6 are results of ANOVA for the vehicle parameters based on the magnitude and area of the pressure measured on pliance. Thus, several statistical parameters can be obtained through ANOVA. Degrees of freedom (DF) indicates the number of independent elements in the sum of squares. The sum of squares (SS) is the deviation of the estimated mean of factor from the overall mean. F-value is an index of F-test which determines whether means of factors are equal or not. The null hypothesis, that means are equal, is rejected by larger F-value. The larger F-value, the higher effect of the factor on that response. P-value indicates the statistical significance of the factor. In this research, the significance level is 0.05 in the 95% confidence. Thus, if P-value is lower than 0.05, the analyzed parameter is not statistically significant according to Fisher's exact test.

Magnitude					
Model	**DF**	**Adj SS**	**Adj MS**	**F-value**	**P-value**
Model	10	1025827	102583	9.2	0
Linear	5	808502	161700	14.5	0
A-pillar to H-point	1	436241	436241	39.13	0
H-point to sill	1	252143	252143	22.62	0
Door open angle	1	94808	94808	8.5	0.004
Door trim extrusion	1	13532	13532	1.21	0.271
Type	1	11778	11778	1.06	0.304
Square	2	111009	55505	4.98	0.007
$\text{A-pillar to H-point}^2$	1	45338	45338	4.07	0.044
H-point to sill^2	1	75051	75051	6.73	0.01
Interaction	3	106315	35438	3.18	0.023
A-pillar to H-point * H-point to sill	1	38713	38713	3.47	0.063
A-pillar to H-point * Door trim extrusion	1	28708	28708	2.58	0.109
Door open angle * Door trim extrusion	1	38894	38894	3.49	0.062
Error	1229	13700897	11148		
Total	1239	14726724			

Table. 5 ANOVA table of magnitude

Area					
Model	**DF**	**Adj SS**	**Adj MS**	**F-value**	**P-value**
Model	10	5334.2	533.42	9.17	0
Linear	5	4030.7	806.13	13.85	0
A-pillar to H-point	1	1640.7	1640.65	28.2	0
H-point to sill	1	1806.8	1806.76	31.05	0
Door open angle	1	483.1	483.08	8.3	0.004
Door trim extrusion	1	48.2	48.15	0.83	0.363
Type	1	52	52.03	0.89	0.345
Square	2	429.8	214.88	3.69	0.025
$\text{A-pillar to H-point}^2$	1	141.1	141.11	2.43	0.12
H-point to sill^2	1	322.8	322.77	5.55	0.019
Interaction	3	873.8	291.26	5.01	0.002
A-pillar to H-point * H-point to sill	1	464.1	464.1	7.98	0.005
A-pillar to H-point * Door trim extrusion	1	212.8	212.75	3.66	0.056
Door open angle * Door trim extrusion	1	196.9	196.91	3.38	0.066
Error	1229	71509	58.18		
Total	1239	76843.1			

Table. 6 ANOVA table of area

In 3rd experiment, parameters are studied in detail using ANOVA. Main and interaction effects of AtH, HtS, DOA, DTE, and Type (SUV and Sedan) are calculated. The result of the stepwise regression analysis is shown in Table. 5 and 6. As a result of the magnitude of pressure, main effects of AtH, HtS, and DOA are statistically significant in the 95% confidence, while those of DTE and Type are not. The result of the area of pressure shows same statistical significances of parameters whether they are in the 95% confidence or not. However, since the aim of this study is to examine the relative influence of parameters, F-values are compared. In the case of the magnitude, relative influence rank is AtH > HtS >> DOA >> Type > DTE. In the case of the area, it is HtS > AtH >> DOA >> DTE > Type. AtH and Hts have overwhelming relative influence, DOA has an influence, and DTE and Type have no influence.

In addition to the main effect, the square and the interaction have significant effects. Even though there are some statistically insignificant terms, they are included in the Table. 5 and 6 because they are considered to have some influence over the other factors excluded as errors. Squared terms, AtH^2 and HtS^2, are all statistically significant in both magnitude and area. In the case of interaction effects, AtH*HtS, AtH*DTE, and DOA*DTE are influential in terms of magnitude and AtH*HtS, AtH*DTE, and DOA*DTE are significant in terms of area. AtH*HtS and AtH*DTE alternate in both magnitude and area. Fig. 9 shows how the result changes as the level of the main effect changes for each parameter. Central composite design, used in 3rd experiment, is one of response surface methodologies that can be optimized. However, as shown in Fig. 9, the farther away the parameter is from the door trim, the less scuff and soil occur. Therefore, in this study, the difference of relative influence among parameters is more concentrated than optimization.

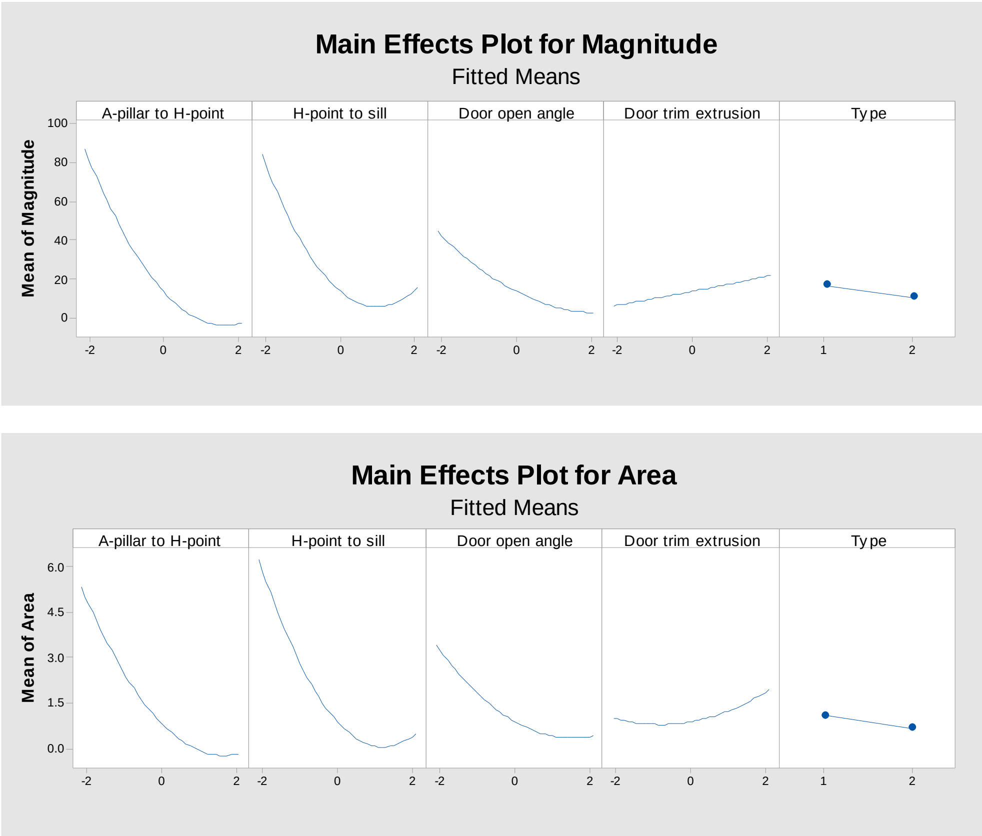
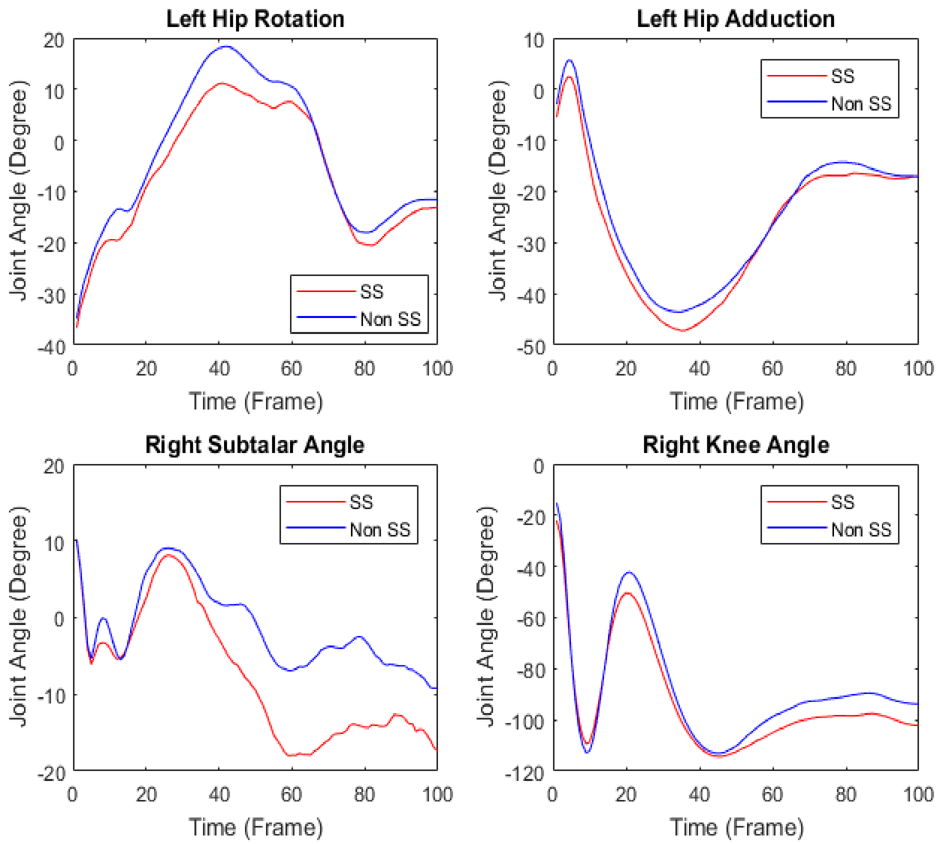


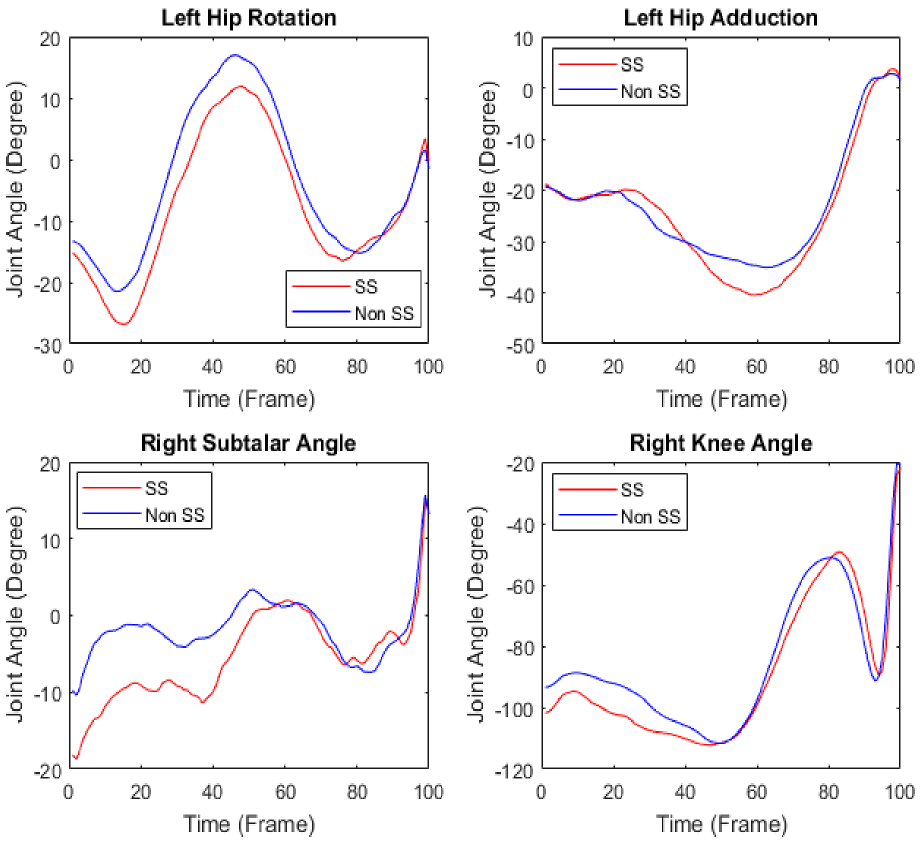
Fig. 9 Main effects plot (Up) Magnitude, (Down) Area

3.4 Motion analysis



* SS: Scuff and Soil, Non SS: Non Scuff and Soil

Fig. 10 Major joint angles (Ingress)



* SS: Scuff and Soil, Non SS: Non Scuff and Soil

Fig. 11 Major joint angles (Egress)

The result of recursive feature elimination based on door trim scuff and soil indicates that four joint movements are significant. They are movements of left hip rotation, left hip adduction, right subtalar, and right knee. Fig. 10 and 11 shows means of four joints angle of ten subjects. SS is the abbreviation of scuff and soil, that causes the door trim scuff and soil while Non SS does not cause.

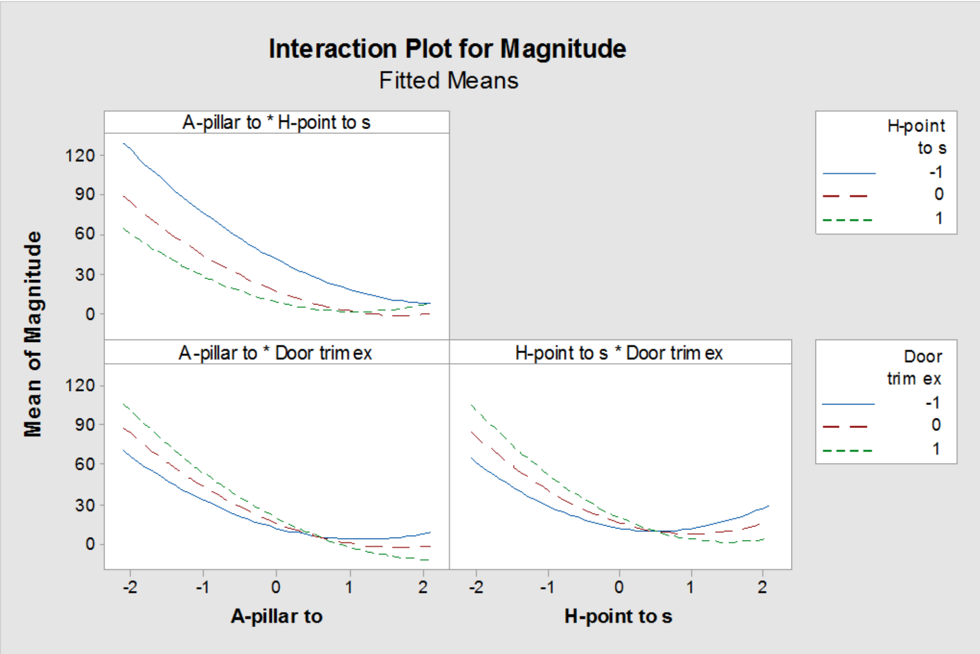
4. Discussion

4.1 Vehicle design method

In this research, after three experiments, key parameters for scuff and soil of vehicle door trim are found. In the 1st experiment, HtG with a relatively small influence is excluded. Also, in the 2nd experiment, SH is excluded. Hence, the 3rd experiment is conducted with selected parameters, AtH, HtS, DOA, and DTE, plus vehicle type parameter. As a result of experiments and ANOVA, AtH and HtS are found to be the most important parameters for door trim scuff and soil. AtH and HtS are dependent on the H-point which refers to the position of the vehicle seat. In Fig. 9, it can be seen that as the position of the seat moves away from the door trim, the degree of scuff and soil decreases. Thus, the change of the position of the seat is most influential on the door trim scuff and soil compared to that of other parameters. It means that AtH and HtS greatly change ingress/egress movements. In other words, the larger the space secured by the position of the seat when ingress/egress, the less scuff and soil of the door trim occur. Therefore, as a solution, ensuring a sufficient space between the steering wheel and the seat during ingress/egress will prevent vehicle interior scuff and soil effectively.

Next to AtH and HtS, DOA is a major parameter to door trim scuff and soil. In the case of DOA, scuff and soil occur at a narrow angle and does not happen at a certain angle or more. Since scuff and soil rarely occur between 1 and 2 levels of DOA, setting the vehicle door checker angle to the size between 1 and 2 levels will minimize the vehicle interior scuff and soil. For further studies, it will be desirable to find the certain angle at which scuff and soil will no longer occur. DTE and Type do not appear to be significant to door trim scuff and soil. In the case of DTE, it is predicted that the more the door trim protrudes, the larger the interference with the foot is. However, the result is not so. Although scuff and soil occur in proportion to the extrusion of door trim, its effect is smaller than other parameters. It means that DTE does not significantly change ingress/egress motion. In the case of Type parameter, there is a slightly more scuff and soil in SUV than in Sedan but the amount is not significant.

In addition to the main effect, the square and interaction effects are observed. First, if the square effect is statistically significant, there is a rising or falling relationship between $parameter^2$ and scuff and soil. In other words, there is a curved relationship between them. For example, in Fig. 9, lines of AtH and HtS are curved because AtH^2 and HtS^2 are significant. In particular, in the case of Hts, whose square effect is much significant, the degree of scuff and soil decreases as its level increases. However, the degree of scuff and soil is not the minimum when the level is the largest. This means that the position of the seat is not directly proportional to the degree of scuff and soil. In this case, human perception of the door trim can be pointed. When the distance between the seat and the door trim is much small, there is an interference with a high probability. However, when the space is secured, it is important whether or not to recognize the door trim. For example, when HtS is at the 0 level, scuff and soil is minimized because there should have been recognition of the door trim during ingress/egress. However, if there is enough distance that the door trim is not recognizable, subjects will unconsciously spot or scratch the door trim. Despite not as much significant as the square effect of HtS, that of AtH is also attributed to the same reason because AtH represents the distance between the seat and the door trim. Therefore, it is important to properly project the door trim to minimize the door trim scuff and soil.



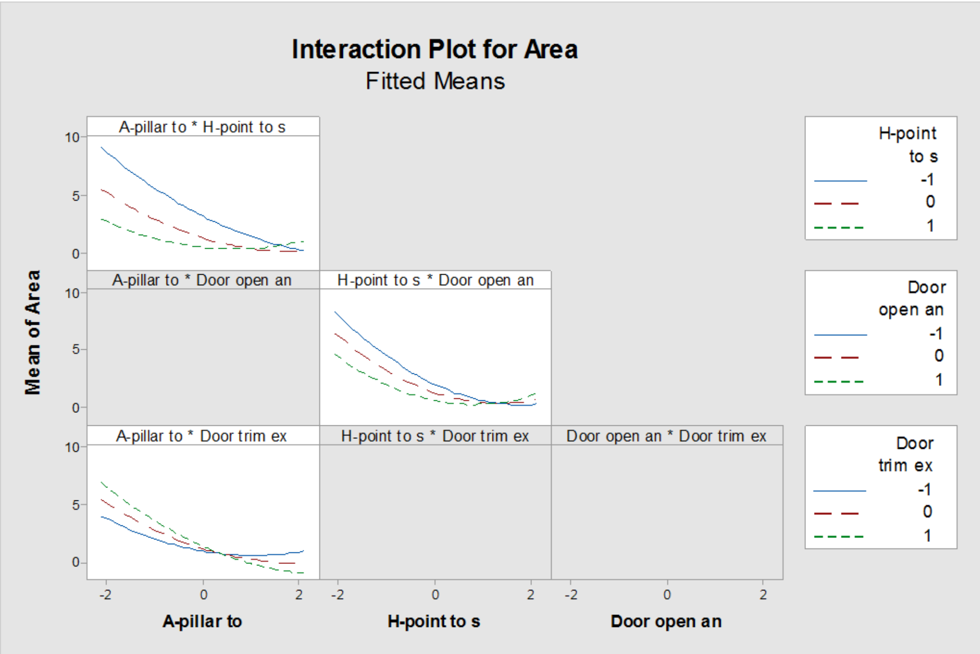


Fig. 12 Interaction plot (Up) Magnitude, (Down) Area

The interaction plot is show in Fig. 12. According to ANOVA table, AtH*HtS of area is the only statistically significant interaction effect in the 95% confidence. However, because there are two overlapping and one different interaction effects between magnitude and area of scuff and soil, it is necessary to analyze interaction effects. First, the interaction effects between AtH and HtS shows that two parameters incur most scuff and soil when they are close to the door trim. However, when AtH is farthest from the door trim, the degree of scuff and soil at the +1 level of HtS is equal (magnitude) or larger (area) than that at -1 and 0 level. In this case, it can be confirmed again whether the recognition of the door trim is important during ingress/egress. If two most influential parameters are located away from the door trim, people are less careful of the door trim scuff and soil because the perception of the door trim is reduced. AtH*DTE is the same. Even though AtH is farthest from the door trim, the degree of scuff and soil is greater at -1 level of DTE than 0 and +1 level of DTE. This can also be explained by the lack of recognition of the door trim. For HtS*DTE and HtS*DOA, they are all in the same context.

* AVG: average

Subject			Scuff and Soil				
No.	**Height** $(\boldsymbol{cm})$	**Weight** $(\boldsymbol{kg})$	**SUV** $(\boldsymbol{No.})$	**Percent** (%)	**Sedan** $(\boldsymbol{No.})$	**Percent** (%)	**AVG** (%)
1	184	78	0	0	0	0	0
2	182	99	0	0	0	0	0
3	177	65	17	30.91	2	3.64	17.27
4	185	77	26	47.28	16	29.1	38.18
5	175	65	20	36.37	14	25.46	30.91
6	178	72	18	32.73	9	16.37	24.55
7	178	68	5	9.1	10	18.19	13.64
8	178	84	9	16.37	14	25.46	20.91
9	177	70	25	45.46	8	14.55	30
10	186	75	16	29.1	4	7.28	18.18
AVG	180	75.3	13.6	24.73	7.7	14.01	19.36

Table. 7 Number and rate of scuff and soil by subject

Scuff and soil rate of the door trim by subject is analyzed. Scuff and soil rate means $(\mathrm{No.\,of\ scuff\ and\ soil} \div \mathrm{No.\,of\ ingress/egress}) \times 100$. Overall, scuff and soil rate is 19.36%, 24.73% for SUV and 14.01% for Sedan. Although, as a result of ANOVA, Type parameter is not statistically significant, there are more numbers of scuff and soil occurred in SUV. Moreover, out of eight subjects who occur scuff and soil, six cause more scuff and soil in SUV than Sedan. It is because the ingress/egress motion of SUV is bigger than that of Sedan. Door trim scuff and soil occurs mainly during the process of raising the right foot from the ground to the vehicle for ingress and lowering the left foot from the vehicle to the ground for egress. Thus, it appears that more scuff and soil are generated in SUV whose operation range of ingress/egress is larger than Sedan. Furthermore, the rate of scuff and soil for each subject (excluding two subjects who do not occur scuff and soil) is 13.64% for minimum and 38.18% for maximum. It varies from person to person, but there is no relationship with height and weight.

4.2 Ingress/Egress motion analysis

* SS: Scuff and Soil, Non SS: Non Scuff and Soil

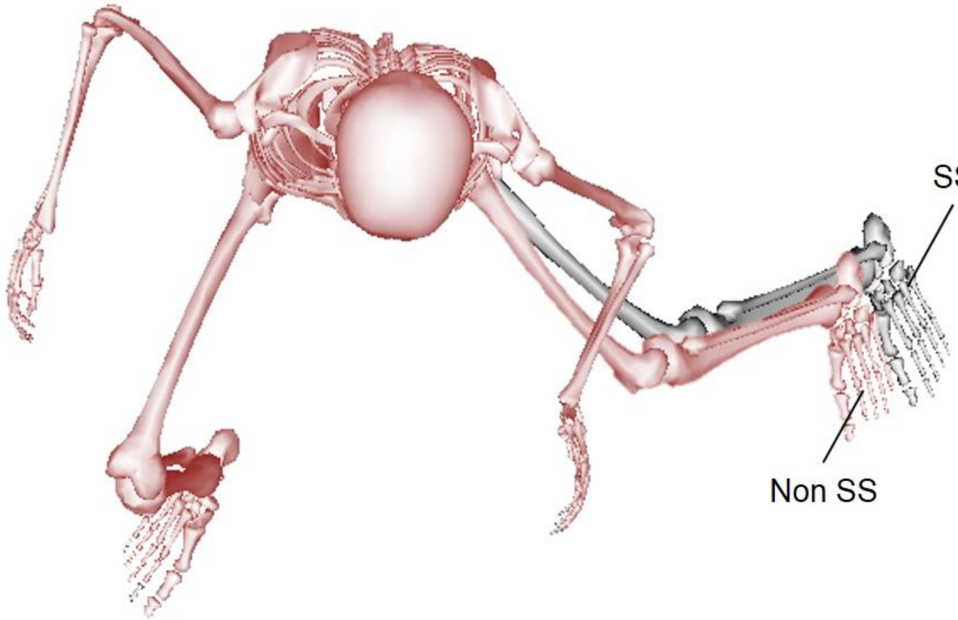


Fig. 13 Hip motion difference between SS and Non SS

* SS: Scuff and Soil, Non SS: Non Scuff and Soil

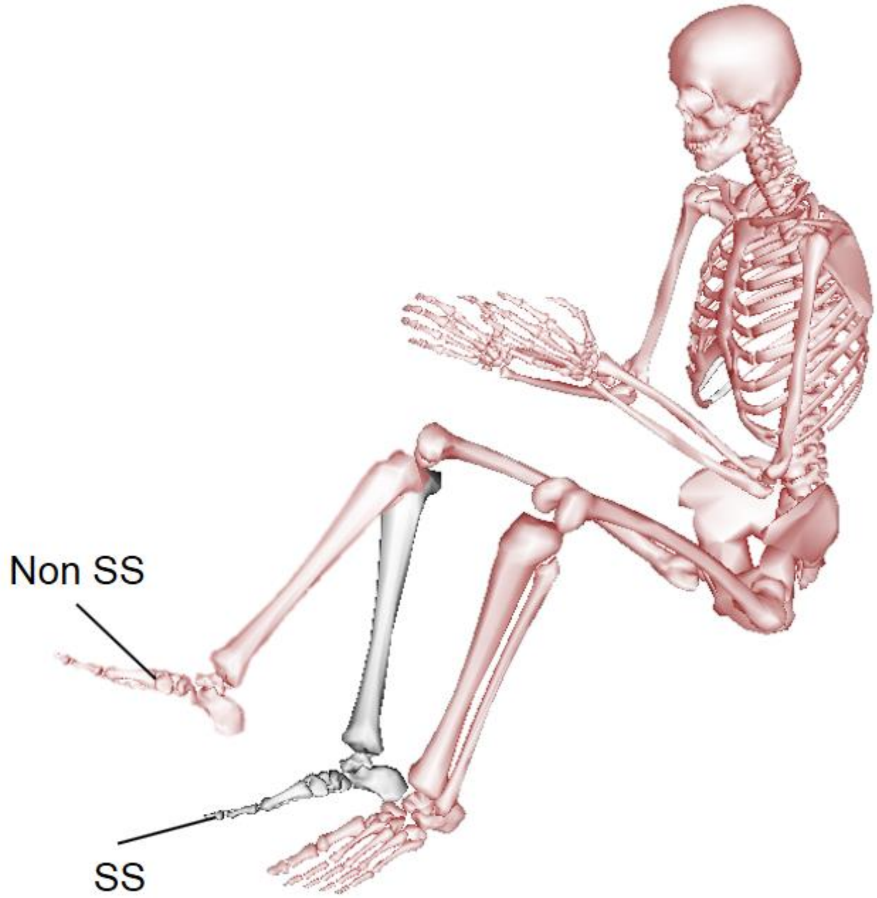


Fig. 14 Knee motion difference between SS and Non SS

* SS: Scuff and Soil, Non SS: Non Scuff and Soil

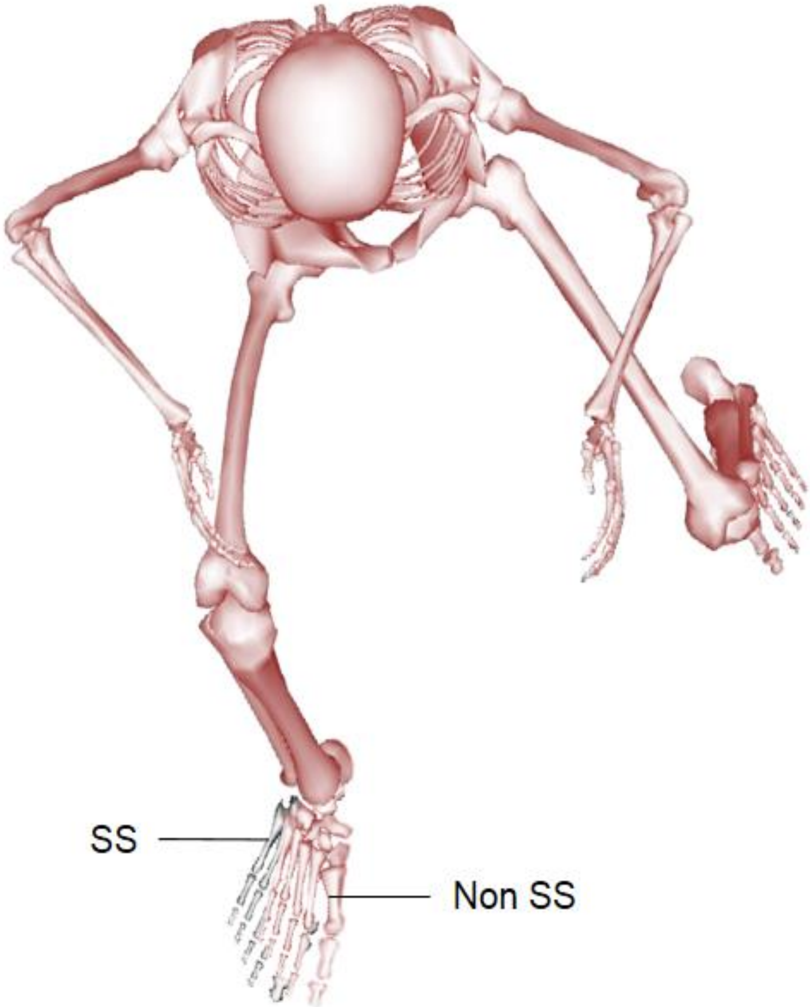


Fig. 15 Subtalar motion difference between SS and Non SS

The overall motion of legs is determined by the hip joint. Fig. 13 is the above view of ingress operation of the 40 frame section shown in Fig. 10, where the difference between SS (Scuff and Soil) and Non SS (Non Scuff and Soil) is the largest for left hip rotation. It is an ingress process that puts the right leg in the driver's seat and is ready to raise left leg. In this term, the left leg of SS, which cause door trim scuff and soil, is further outward. Similarly, left hip adduction shows that the left leg of SS is more outward than that of Non SS when its joint angle is the most different between SS and Non SS. Therefore, door trim scuff and soil is mainly caused by the left leg.

Fig. 14 is the section where the difference of knee joint angles between SS and Non SS is the largest. It is the state of sitting on the driver's seat, not the process of ingress/egress. In the case of Non SS, knee joints are able to be stretched. It means that the legroom of the driver's seat secured much space. In this case, there is high probability of scuff and soil when knee joints cannot be extended sufficiently, that is, when the legroom is narrow. Hence, the size of the legroom space affects door trim scuff and soil. Following Fig. 15, there is a difference of the position of subtalar joint in the process of supporting the right leg while trying to put the left leg into the driver's seat during ingress. The subtalar joint of SS is located quite more outward than Non SS. This is a situation that the subtalar joint is further turned outward so that the center of the right leg is further exerted at ingress. Therefore, door trim scuff and soil occurs in the motion to get more balance of the body.

4.3 Limitation

I would like to point out some limitations of the present study. First, in this research, door trim scuff and soil occur only when pressure is measured by pliance attached to the door trim. Thus, if the pressure pad is not bumped, it can be said that door trim scuff and soil do not occur. However, even if scuff and soil do not happen, nearly happened case and hardly happened case will surely exist. In this study, two cases are regarded as the same way, so the possibility of scuff and soil is not accurately measured. In future studies, it is necessary to define the probability of scuff and soil by adding new measurement criteria such as foot and the door trim distance. Second, only young and healthy male subjects are recruited. If the population should be even regardless of gender, age, and health, results of study will be reliable, improved and applied broadly. Third, the size of the pressure pad measuring the degree of scuff and soil is limited. Due to hardware limitations, it is impossible to cover the entire door trim, so it can not be determined if interference occurs where pressure pad is not attached. In further research, more pressure sensors should be implemented on the rest of door trim as well as other vehicle interior materials. Fourth, more vehicle parameters should be investigated. In this study, I concentrated on several parameters and improved the depth and robustness of the results. However, more parameters can be considered with fewer experiments by applying Taguchi's method or Plackett-Burman design.

5. Conclusion

In order to minimize vehicle door trim scuff and soil, main vehicle parameters are found through experiments and ingress/egress motion is analyzed to understand the cause. After three-time experiments, of six vehicle parameters, A-pillar to H-point, H-point to sill, and Door open angle are significant to door trim scuff and soil while H-point to ground, Sill height, and Door trim extrusion are not. When analyzing ingress/egress motion, left hip rotation, left hip adduction, right subtalar, and right knee joint movements are major in door trim scuff and soil. These results will be of great help in understanding the chronic problem of vehicle interior scuff and soil and designing the vehicle in direction of minimizing scuff and soil.

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초 록

인간공학적 설계는 자동차 업계에서 중요시 되고 있다. 자동차 내장재가 더러워진다면 사람의 감성은 영향을 받을 것이다. J.D. Power에 따르면 자동차 내장재 오염이 고질적인 문제임에도 불구하고, 그에 대한 해결방안은 표면처리 또는 재료적인 측면으로만 제한되어있다. 따라서 내장재 오염을 방지하기위해, 본 연구에서는 자동차 승/하차 동작을 이용한 인간공학적 해결방안을 제시한다. 우선 내장재 오염에 대한 자동차 설계 파라미터들의 영향도를 분석했다. 여기서 내장재 오염은 도어트림에 부착한 압력패드로 측정한다. 본 연구에서는 내장재 중에서도 가장 오염이 많이 일어나는 도어트림에 집중하기로한다. 승/하차 동작 실험은 직접 설계하고 제작한 자동차 mock-up을 이용하여 총 3번 진행했다. Mock-up은 관성식 모션캡쳐 장비를 이용하여 실제 자동차와 유사한 환경을 제공한다고 검증을 거쳤다. 실험초기에는 6개의 설계파라미터를 고려하였고, 1/2 정규확률도를 이용하여 하나의 실험마다 영향도가 낮은 하나의 파라미터를 제외하였다. 따라서 3차 실험에서는 4개의 자동차 설계 파라미터와 차종 파리미터를 추가하여 그에 대한 영향도를 ANOVA를 이용하여 분석하였다. 각 실험은 실험계획법에 기초하였다. 수준별 치수들은 현실적인 범위에서 가장 크게 잡았다. A-pillar to H-point, H-point to sill, Door open angle의 3개 파라미터가 가장 오염에 주요한 변수로 나타났다. H-point to ground, Sill height, Door trim extrusion의 3개 파라미터는 주요하지 않게 나타났다. 3차 실험에서는

광학식 모션캡쳐 시스템을 이용하여 승/하차 동작 데이터를 획득했다. 이 데이터를 기반으로 recursive feature elimination을이용하여, 오염에 주요한 관절 동작을 구했다. Classification 알고리즘은 KNN 알고리즘을 이용하였다. Hip, knee, subtalar 움직임이 오염에 가장 주요했다. 따라서 자동차 설계 파라미터와 승/하차 동작 분석은 자동차 설계자로부터 내장재 오염을 최소화시킬 수 있는 방향으로 자동차를 설계하고, 그 오염이 왜 일어나는지에 대한 이해를 시켜줄 수 있을 것이다.

주요어: 자동차 승/하차 동작, 자동차 도어트림, 오염, 동작분석

학번: 2016-20719