JESK J Ergon Soc Korea 2017; 36(2): 69-86
http://dx.doi.org/10.5143/JESK.2017.36.2.69
http://jesk.or.kr eISSN:2093-8462

Ergonomic Evaluation and Improvement of Bus Seat Armrest Design

Hayoung Jung[1], Seunghoon Lee[1], Moonjin Kim[2], Hoimin Choi[2], Heecheon You[1]

[1]POSTECH, Department of Industrial and Management Engineering, Pohang, 37673
[2]Hyundai Motor Group, Division of Bus Body Engineering Team, Hwaseong, 18270

Corresponding Author
Heecheon You
POSTECH, Department of Industrial and Management Engineering, Pohang, 37673
Mobile : +82-10-3213-2210
Email : hcyou@postech.ac.kr

Received : September 02, 2016
Revised : September 11, 2016
Accepted : December 09, 2016

Objective: The present study is intended to develop an improved bus seat armrest design by evaluating various bus armrest designs from ergonomic aspects.

Background: An ergonomic armrest design which considers the sitting postures and body shapes of passengers can improve the convenience and comfort of a bus seat.

Method: Subjective satisfaction of each of five design dimensions (length, width, height from seatpan, shape, and angle) was evaluated for seven bus seat armrest designs in various sizes and shapes by 58 participants (28 males and 33 females) using a 7-point scale (1: very dissatisfied, 4: neutral, and 7: very satisfied). Improved bus seat armrest designs adjustable in length and rotatable to the left or right (sliding and rotating armrest, SRA) with a concave, flat, or convex shape of the upper part were developed by considering the preferred design features and the body size and shape in sitting posture and needs of passengers and then compared with a conventional armrest.

Results: A bus seat armrest with a wide width (40~50mm), a long length (360mm), a lower height (213mm), and a curved shape was found significantly preferred in terms of comfort. The proposed armrest designs (SRA-convex, SRA-flat, and SRA-concave) improved satisfaction by 46~62% for length suitability, 184~216% for width suitability, 205~214% for angle suitability, 138~181% for contact area suitability, and 49~64% for height suitability, 138~174% for comfort, and 93~111% for overall satisfaction.

Conclusion: The preferred design features and passengers' needs of bus seat armrest were identified and the SRA designs were recommended for better usability.

Application: The ergonomic design process of bus seat armrest employed in the present study can be applied to designing armrests in various vehicles for better convenience and comfort.

Keywords: Ergonomic armrest design, Human body shape, Shape analysis, Product development, Armrest size and location

Copyright@2017 by Ergonomics Society of Korea. All right reserved.

This is an open-access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (http://creativecommons.org/licenses/by-nc/3.0/), which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

1. Introduction

An armrest can affect the usability of the bus passenger seat by supporting the passenger's arm to remain in the seat, distribute body pressure, and maintain a comfortable posture. The armrest of bus passenger seat is placed on the side of the passenger to support the lateral upper body and the lower arm from the centrifugal

force produced when the bus is driven on a curve and prevent the passenger from diverting from the seat (Son et al., 2015). The use of armrest reduces the seating pressure on the arm and spine by distributing the pressure acting on the upper body of the passenger (Bush and Hubbard, 2007; Nag et al., 2008). The bus seat armrest supports the lower arm when seated and helps the passenger maintain a comfortable posture by inducing a natural upper body posture (Nag et al., 2013; Van Veen et al., 2014). Finally, design factors such as the size, shape, position, and material properties of bus seat armrest affect seating comfort and armrest usability (Zhao and Tang, 1994; Kolich, 2003).

Ergonomic evaluation studies on armrest have been performed in terms of muscular load (EMG), body pressure distribution, postural stability, and perceived discomfort. Hasegawa and Kumashiro (1998) reported that use of armrest of which height is adjustable from 22.0cm to 28.0cm reduced the muscle load (EMG) of upper trapezius, middle trapezius, and biceps brachii of the arm significantly compared to no use of armrest. Nag et al. (2008) showed that the weight on the seatpan decreased by 4.2kg (from 38.3kg to 34.1kg; 11.0%) by use of armrest (armrest height = 23.5cm) compared to no use of armrest and the body weight of the seatpan decreased by 2.2kg, 4.0 kg and 4.1kg as the height of an armrest was positioned to 21.5cm, 25.5cm, and 27.5cm, respectively, in an office chair. Nag et al. (2013) showed that the medio-lateral center of pressure displacement decreased by 3.8mm (from 11.4mm to 7.6mm) as the height of the armrest increased from 17.0cm to 23.0cm when a height adjustable armrest was used in an office chair, which indicates that the posture stability improved by 33.3%. Lastly, Delisle et al. (2006) found that the discomfort in use of armrest in an office chair decreased by 1.7 (from 4.3 to 2.6; 39.5%) on a 10-point scale compared with no use of armrest.

An ergonomic bus seat armrest can be developed by an analysis on preferred design characteristics of various armrest design factors (e.g., size, shape, and position). Usability evaluation studies on armrest have been conducted mostly for office chairs, not for bus passenger seats, in terms of muscular load (EMG), seating pressure distribution, postural stability, satisfaction, and discomfort. The user satisfaction, preference, and seating comfort of a bus seat armrest can be improved by benchmarking various armrest designs of bus passenger seat. In the evaluation of armrests, the anthropometric characteristics of the lower arm, use characteristics of armrest, tasks in seating, and various satisfaction criteria need to be considered in an integrated manner (Hasegawa and Kumashiro, 1998; Mahmoudi and Bazrafshan, 2013; Nag et al., 2013; Park et al., 2015). Existing research has evaluated changes in musculoskeletal load and discomfort by armrest position such as height of armrest (Hasegawa and Kumashiro, 1998; Nag et al., 2013; Vos et al., 2006) and distance between left and right armrests (Fredericks et al., 2014; Groenesteijin et al., 2012; Mahmoudi and Bazrafshan, 2013; McCormick and Tubergen, 2003). However, no research has been conducted regarding the effects of armrest size and shape such as length, width, and curvature on satisfaction.

The present study is intended to identify the preferred characteristics of armrest design factors including length, height, width, and shape for better usability and to validate the identified preferred design characteristics using prototypes. In this study, the analyses of satisfaction and voice of customer (VOC) were performed on seven armrest designs in various sizes and shapes, and then the effects of armrest design characteristics on seat comfort and preferred design characteristics of armrest were examined. Novel designs of bus seat armrest were proposed by considering ideas generated based on user needs and ergonomic aspects such as the shape of the upper arm and seating posture. Lastly, the proposed armrest designs were compared with a conventional armrest design in terms of subjective satisfaction.

2. Ergonomic Evaluation of Bus Seat Armrest

2.1 Methods

2.1.1 Participants

A total of 58 participants (male: 28, female: 33) in various body sizes and ages (20~50s) were recruited in subjective evaluation

of armrest designs. Nine groups in combination of three height categories (small: < 33rd %ile; medium: 33rd %ile ~ 66th %ile; large: > 66th %ile) and three equivalent weight categories were formed for each gender. Participants were recruited by considering the bivaraiate distribution of height and weight of Koreans while 12~15 participants being recruited in each age group. The cutoffs of height and weight were as follows: 168.8cm for 33rd %ile and 174.0cm for 66th %ile for male height; 66.3kg for 33rd %ile and 75.2kg for 66th %ile for male weight; 156.1cm for 33rd %ile and 160.9cm for 66th %ile for female height; 52.2kg for 33rd %ile and 58.8kg for 66th %ile for female weight. The height (165.0 ± 8.7cm), seated elbow height (26.0 ± 2.6cm), and weight (65.9 ± 13.3kg) of the participants were found statistically similar in terms of mean and variability to the height (165.4 ± 8.8cm; t[4584] = 0.44, p = 0.65; F[4537, 47] = 0.98, p = 0.43), seated elbow height (25.9 ± 2.4cm; t[4584] = 0.79, p = 0.43; F[4537, 47] = 1.12, p = 0.69), and weight (64.5 ± 12.1kg; t[4584] = 0.43, p = 0.67; F[4537, 47] = 1.21, p = 0.79) of the corresponding groups of Koreans (n = 4538) reported in the 2010 Size Korea anthropometric survey (KATS, 2010). Each participant provided informed consent to the experiment.

2.1.2 Experiment environment and apparatus

For ergonomic passenger seat armrest evaluation, seven armrests were installed in a seating buck of bus passenger seat which provides a similar vehicle environment by considering the indoor space of the bus. The seating buck of the bus passenger seat was fabricated in a width of 2,370mm, similar to the width of a bus, and bus passenger seats were arranged in two lines in the seating buck. The back-and-forth clearance and lateral clearance between passenger seats were set to 850mm and 660mm, respectively. The seating buck also had windows on its left and right sides as shown in Figure 1 to provide a sitting environment similar to the actual bus.

Figure 1. Seating buck for bus seat armrest evaluation

2.1.3 Armrests

A total of seven bus seat armrests (Figure 2) in various lengths, widths, and heights were selected in the present study and their design specifications were analyzed as shown in Table 1. The length, width, and height (distance to the highest point of armrest

from the lowest point of seating surface) of each armrest were measured. It was identified that their length, width, and height ranged 255~360mm, 35~60mm, and 213~263mm, respectively, and their side shapes were either linear or curved.

Figure 2. Armrests of bus passenger seat selected for ergonomic evaluation

Table 1. Specifications of bus passenger seat armrests considered in ergonomic evaluation

Armrest model*	Length (mm)	Width (mm)	Height from the seating surface (mm)	Cross-section shape
AR1	290	40	260	Linear
AR2	255	35	240	Linear
AR3	260	50	213	Linear
AR4	300	40	240	Curved
AR5	300	45	235	Curved
AR6	330	45	239	Curved
AR7	360	45	263	Curved

* Refer to Figure 2 for armrest models considered in the ergonomic evaluation.

2.1.4 Evaluation protocol

A satisfaction evaluation of the bus seat armrests was conducted using a 7-point scale (1: very dissatisfied, 4: neutral, and 7: very satisfied) by a participant in sitting and VOCs were collected. An evaluation questionnaire of bus seat armrest (Figure 3) was prepared by including five biomechanical aspects such as length suitability, width suitability, height suitability from the seat surface, form conformity, and overall satisfaction, which were selected by referring to existing seat comfort evaluation studies (Kim et al., 2010; Kolich, 2003; Smith et al., 2006). In the armrest evaluation, comments on likes and dislikes on the armrests were also surveyed. The armrest evaluation was performed in a seating posture of 18° of backrest angle by referring to the evaluation method of bus passenger seat comfort of Park et al. (2015). In this study, VOCs were collected for preferred design characteristics of armrests and frequencies of VOCs and priorities of improvements were analyzed.

Subjective Evaluation Questionnaire for Bus Seat Armrest

Criteria		Reason for Satisfaction/ dissatisfaction	Armrest Type						
			Armrest 1	Armrest 2	Armrest 3	Armrest 4	Armrest 5	Armrest 6	Armrest 7
Height suitability: degree of appropriate height of armrest when sitting		Very satisfied	⑦	⑦	⑦	⑦	⑦	⑦	⑦
		Satisfied	⑥	⑥	⑥	⑥	⑥	⑥	⑥
		Slightly satisfied	⑤	⑤	⑤	⑤	⑤	⑤	⑤
		Neutral	④	④	④	④	④	④	④
		Slightly dissatisfied	③	③	③	③	③	③	③
		Dissatisfied	②	②	②	②	②	②	②
		Very dissatisfied	①	①	①	①	①	①	①
Reason for dissatisfaction	If the height of the armrest is not appropriate for sitting, why?	Very high	+3	+3	+3	+3	+3	+3	+3
		High	+2	+2	+2	+2	+2	+2	+2
		Slightly high	+1	+1	+1	+1	+1	+1	+1
		Slightly low	-1	-1	-1	-1	-1	-1	-1
		Low	-2	-2	-2	-2	-2	-2	-2
		Very low	-3	-3	-3	-3	-3	-3	-3
Width suitability: degree of appropriate width of armrest when sitting		Very satisfied	⑦	⑦	⑦	⑦	⑦	⑦	⑦
		Satisfied	⑥	⑥	⑥	⑥	⑥	⑥	⑥
		Slightly satisfied	⑤	⑤	⑤	⑤	⑤	⑤	⑤
		Neutral	④	④	④	④	④	④	④
		Slightly dissatisfied	③	③	③	③	③	③	③
		Dissatisfied	②	②	②	②	②	②	②
		Very dissatisfied	①	①	①	①	①	①	①
Reason for dissatisfaction	If the width of the armrest is not appropriate for sitting, why?	Very wide	+3	+3	+3	+3	+3	+3	+3
		Wide	+2	+2	+2	+2	+2	+2	+2
		Slightly wide	+1	+1	+1	+1	+1	+1	+1
		Slightly narrow	-1	-1	-1	-1	-1	-1	-1
		Narrow	-2	-2	-2	-2	-2	-2	-2
		Very narrow	-3	-3	-3	-3	-3	-3	-3

Figure 3. Subjective evaluation questionnaire for bus seat armrest

2.1.5 Statistical Analysis

ANOVA was conducted to identify the effects of armrest design characteristics on subjective satisfaction. The difference in preference by armrest design was analyzed by one-way ANOVA and then the Tukey-Kramer test was conducted at 0.05 of significance level as post-hoc analysis. Minitab v.14 was utilized for statistical analysis in the present study.

2.2 Evaluation results of bus seat armrest

Armrests with a wide width, a long length, a low height from the seat pan, and a curved shape were found preferred (Figures 4 to 7). As shown in Figure 4, the armrests with a width of 40 to 50mm (AR 1 and ARs 3 to 7; mean satisfaction = 4.3) were found preferred in terms of width suitability to the armrest with a width of 35mm (AR 2; mean satisfaction = 2.9) (F[6, 358] = 7.70; p < 0.001). Also, the highest proportion (34%) of participants showing dissatisfaction (≤ 2) was reported in the armrest width 35mm (AR 2) while the dissatisfaction percentages ranged 20~29% for the other wider armrest widths. Also the survey on the adequacy of bus armrest width showed that all the armrests were evaluated as -1.3 ~ -1.7 (indicating slightly narrow), which indicates that an armrest with a wide width would be preferred.

As shown in Figure 5, the bus armrest with a length of 360mm (AR 7; mean satisfaction = 4.9) was found significantly preferred in terms of length suitability compared to armrests with a length of 255 to 269mm (ARs 2 and 3; mean satisfaction = 3.6) (F[6, 358] = 4.41; p < 0.001). The proportion of dissatisfied respondents was 28% for the armrest length of 255mm (AR 2), which is 12~21% higher than the other armrest lengths. The questionnaire survey on the adequacy of armrest length showed that all the armrests

except for the armrest with a length of 360mm (AR 7) were evaluated as -1.0 to -1.7 (indicating slightly short), which indicates that a long length of armrest would be preferred.

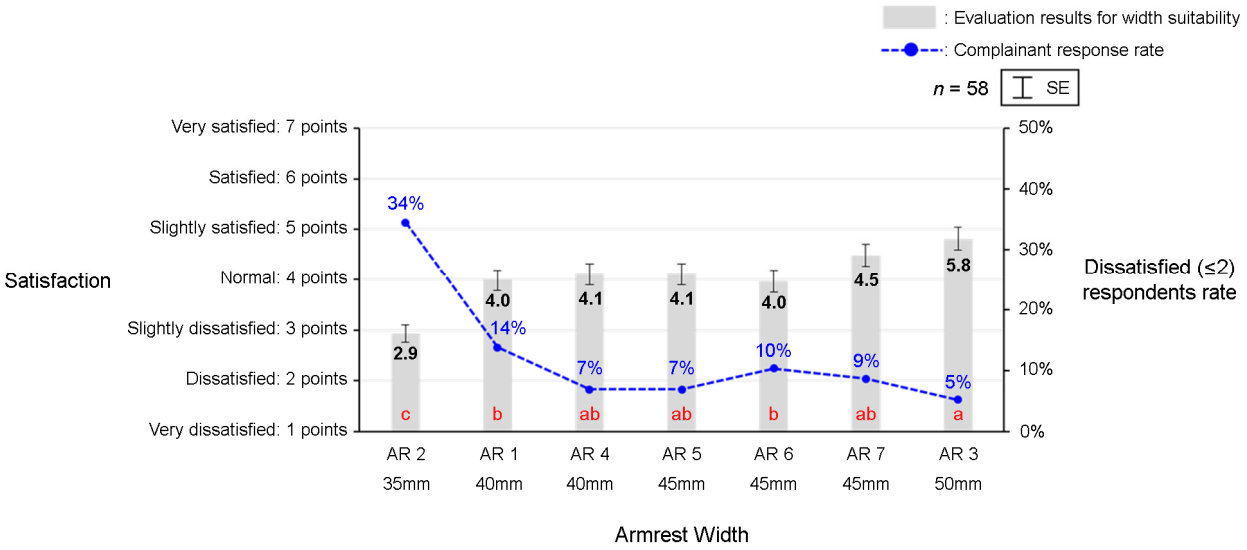

Figure 4. Mean satisfaction and percentage of dissatisfied (≤ 2) respondents on the width suitability of bus seat armrest

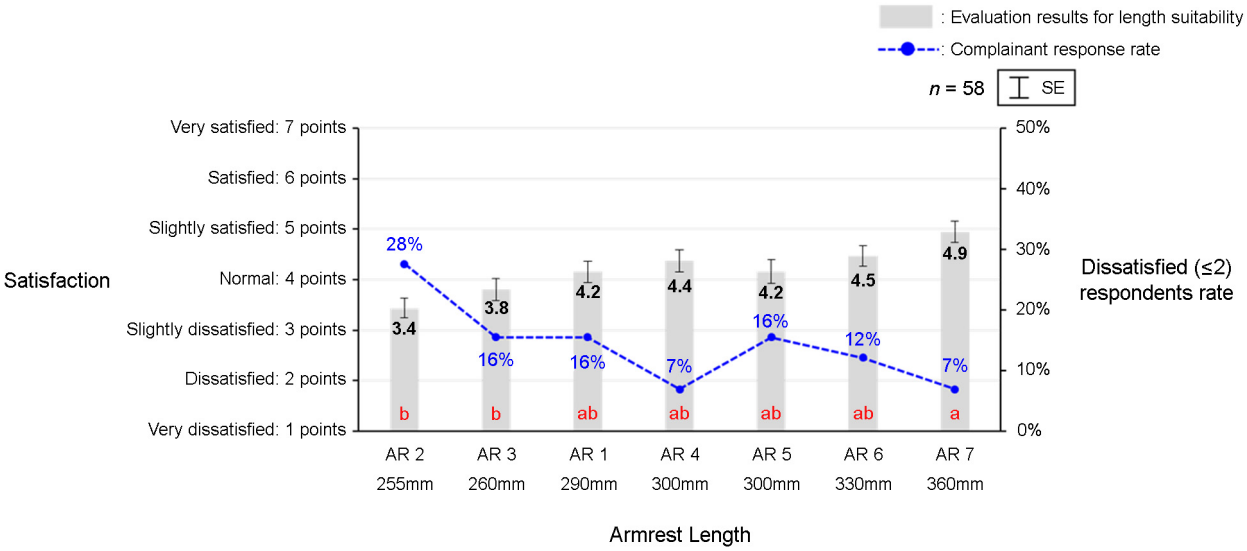

Figure 5. Mean satisfaction and percentage of dissatisfied (≤ 2) respondents on the length suitability of bus seat armrest

As shown in Figure 6, the armrest with a height from the seat pan of 213mm (AR 3; mean satisfaction = 5.1) was found preferred in terms of height suitability compared to the other armrests (mean satisfaction = 4.2) with heights of 235 to 263 mm (F[6, 358] = 4.41; p < 0.001). The proportion of dissatisfied respondents was 14% for the armrest height of 255mm (AR 2), which is 2~7% higher than the other armrest lengths. The percentages of dissatisfied respondents were decreased in order of AR 5 (12%), AR 6

(12%), AR 2 (10%), AR 4 (9%), AR 1 (7%), and AR 3 (7%). The questionnaire survey on the adequacy of armrest height showed that the armrest with a height of 213 mm was evaluated as -0.9 (indicating slightly low) and the other armrests with heights of 235 to 263 mm were evaluated as 1.0 to 1.5 (indicating slightly high).

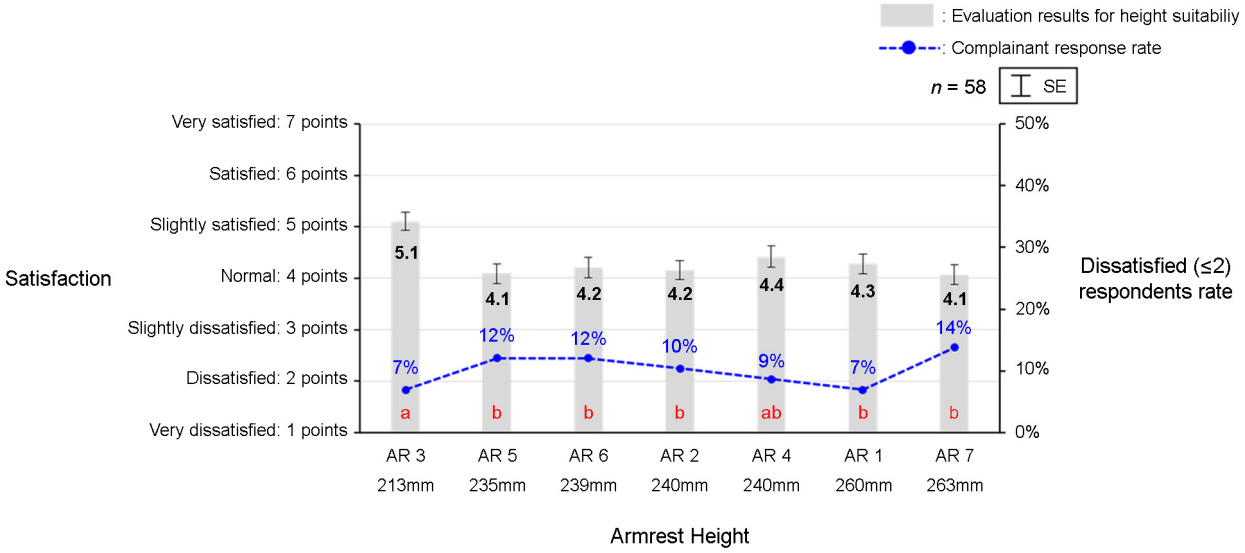

Figure 6. Mean satisfaction and percentage of dissatisfied (≤ 2) respondents on the height suitability of bus seat armrest

As shown in Figure 7, the bus passenger armrests with a curved cross-sectional shape (ARs 4 to 7, mean satisfaction = 4.7) were found preferred in terms of form conformity to those with a straight cross-sectional shape (AR 1, AR 2, AR 3; mean satisfaction = 4.2) (F[1, 393] = 9.15; p = 0.003). The proportion of dissatisfied respondents was 17% in armrest with straight cross-sectional

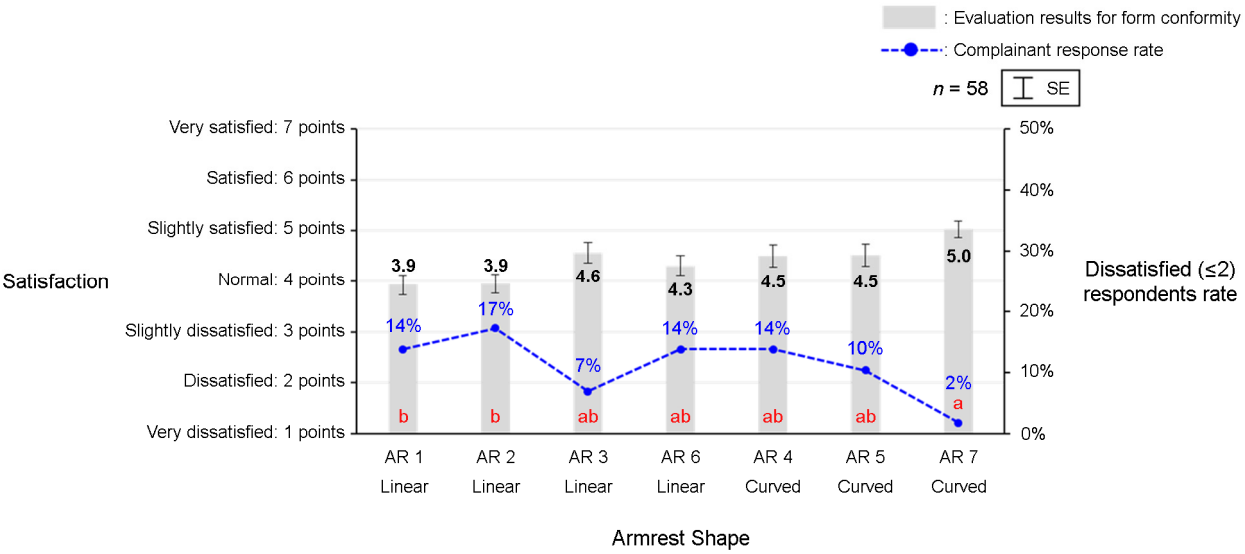

Figure 7. Mean satisfaction and percentage of the dissatisfied (≤ 2) respondents on the form conformity of bus seat armrest

shape (AR 2), which is 3~15% higher than the curved armrest shape. The percentages of the dissatisfied respondents decreased in order of AR 1 (14%), AR 4 (14%), AR 6 (14%), AR 5 (10%), AR 3 (7%), and AR 7 (2%).

As shown in Figure 8, the highest overall satisfaction was rated for AR 7 (mean satisfaction = 4.9) followed by AR 3 (4.6), AR 4 (4.3), AR 5 (4.2), AR 6 (4.2), AR 1 (4.0), and AR 2 (3.4) in order. The highest proportion of the dissatisfied respondents in terms of overall satisfaction was obtained by 26% in AR 2, which is 12~24% higher than other armrests. The percentages of the dissatisfied respondents with the armrests decreased in order of AR 5 (14%), AR 1 (12%), AR 5 (10%), AR 3 (7%), AR 6 (7%), and AR 7 (2%).

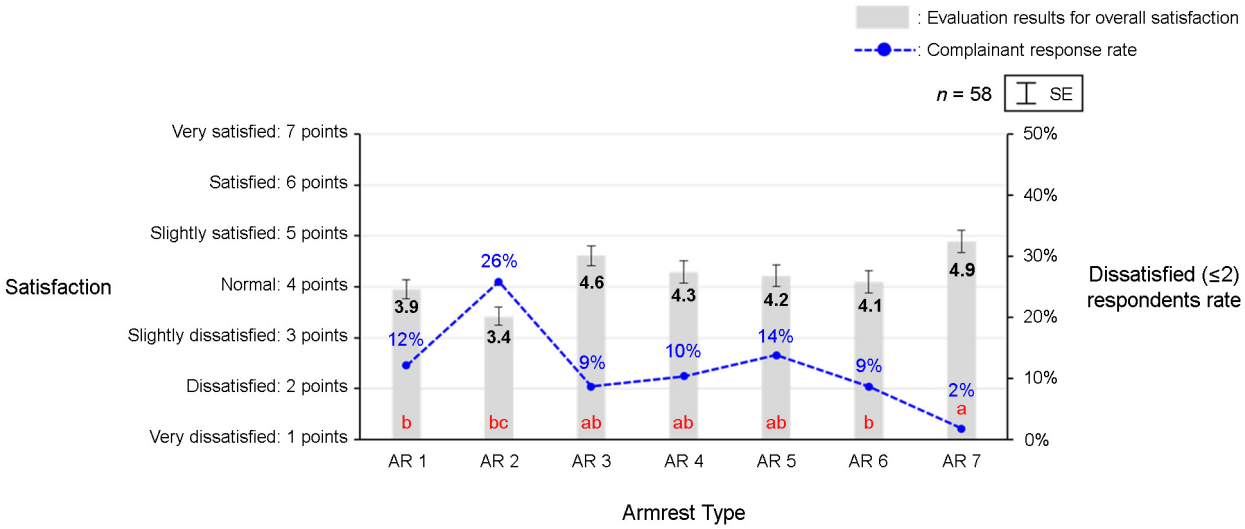

Figure 8. Mean satisfaction and percentage of the dissatisfied (≤ 2) respondents on the overall satisfaction of bus seat armrest

An analysis on the VOCs collected in the study showed that the armrest of bus passenger seat needs to be improved in terms of width (26.7%), height (26.4%), length (18.5%), and shape (18.5%) as shown in Table 2. In the armrest evaluation, 146 comments for improvement were collected on the design characteristics of armrest height, length, width, angle, shape, and material. A total of 39 unfavorable comments on a narrow width of armrest indicated the width of armrest needs to be wider. Next, a total of 32 unfavorable comments on a high armrest and 4 on an unadjustable armrest in height indicated the height of armrest needs to be lower and/or adjustable. Then, a total of 22 unfavorable comments on a short armrest and 5 on a long armrest indicated the length of armrest needs to be adjustable. A total of 19 unfavorable comments on a linear shape of armrest and 8 on a sharp edge of armrest indicated that the cross-section shape of armrest needs to be redesigned. Lastly, 5 unfavorable comments on slippery material of armrest, 5 on rough surface of armrest, 4 on a steep angle of armrest, and 2 on an unstable armrest indicated the material, surface finish, angle, and stability of armrest need to be improved.

Table 2. Analysis of comments on unfavorable armrest designs

Design factor	Unfavorable design characteristics	Frequency	%
Width	Narrow armrest width	39	26.7
Height	High armrest height	32	21.9

Table 2. Analysis of comments on unfavorable armrest designs (Continued)

Design factor	Unfavorable design characteristics	Frequency	%
Height	Low armrest height	1	0.7
	Unadjustable armrest height	4	2.7
Length	Long armrest length	22	15.1
	Short armrest length	5	3.4
Shape	Liner armrest side profile	19	13.0
	Sharp edged armrest	8	5.5
Material	Slippery material	5	3.4
	Rough surface	5	3.4
Angle	Steep angled armrest	4	2.7
Miscellaneous	Armrest cannot be locked	2	1.4
Sum		146	100.0

3. Development and Evaluation of New Bus Seat Armrest

3.1 Development method of new bus seat armrest

As shown in Figure 9, new armrest designs were developed by considering VOCs, armrest usability evaluation results, and ideas and design concepts generated through product design and development process. In the VOC analysis, VOCs of preferred and unfavorable features for armrest design factors such as width, height, length, shape, material, and angle of armrest were identified. In the usability evaluation analysis, preferred design features of armrest in terms of seating comfort were identified by applying the benchmarking method (Park et al., 2015; Lee et al., 2013) for identification of preferred design characteristics based on usability evaluation. For example, AR 3 (50mm), AR 7 (45mm), AR 6 (45mm), AR 5 (45mm), AR 4 (40mm), and AR 1 (40mm) found preferred in terms of armrest width, which resulted in a preferred design range of 40 to 50mm as armrest width. Table 3 shows the preferred design ranges for armrest length, height, shape, angle, and material by applying the preferred design characteristics analysis results. In the development stage of idea and design concept, ergonomic armrest improvement insights and armrest improvement ideas were explored and integrated, resulting in improved armrest design concepts. Ergonomic insights for improvement of armrest were derived by analyzing VOCs with high frequency and improvement requirements for the shape, function, and structure of armrest to satisfy unmet and/or latent needs of users. Based on the derived insights, 55 new ideas of armrest design were developed by documenting illustrations, detailed descriptions, and expected effects for each idea as illustrated in Figure 10. The armrest improvement ideas were screened using a 10-point scale for usability and novelty by five armrest design experts and additional ideas were integrated into a sliding and rotating armrest (SRA) for comprehensive armrest improvement (Figure 11). The SRA design has a curved shape and a rotating and sliding structure to accommodate the body sizes and postures of passengers with the preferred design ranges and armrest improvement ideas (Figure 12). The top surface shape of the SRA design was further examined to accommodate various curved shapes of the lower arms, resulting in three shape alternatives: convex, flat, and concave shapes. The SRA design alternatives were 290 to 360mm in length, 50mm in width and 213mm in height from the seating surface as shown in Table 4. The SRA-Convex was designed with a lateral curvature of 704mm and a frontal curvature of 146mm on the upper surface of armrest and SRA-Concave with a lateral curvature of 586mm and a frontal curvature of 141mm. The corresponding armrest prototypes were designed using CAD software Alias (Autodesk Inc., USA) and fabricated as shown in Figure 10 using the 3D printer Dimension SST (Stratasys Inc., USA).

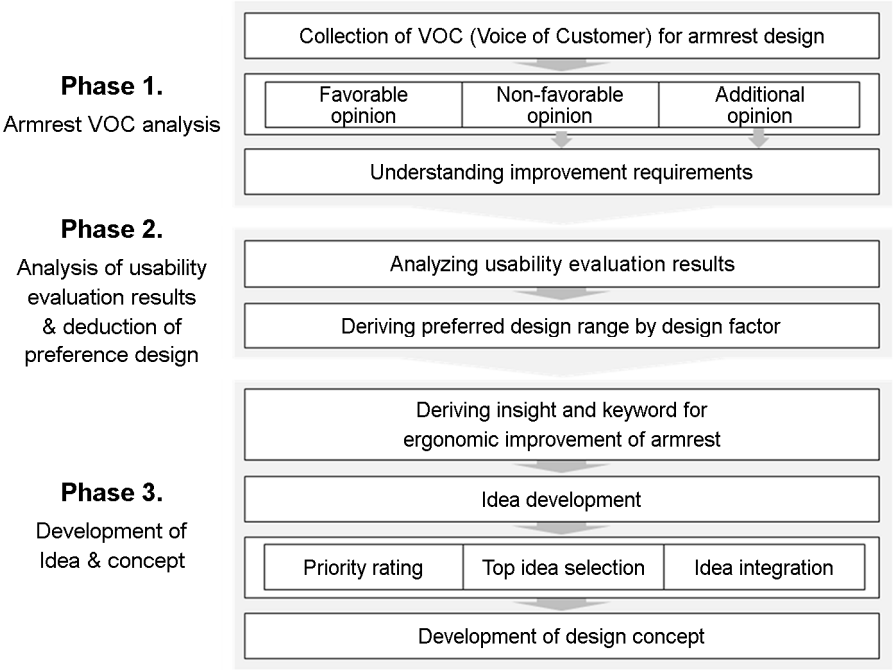

Figure 9. Development process of bus seat armrest improvement

Table 3. Preferred design characteristics by armrest design factor

Design factor	Reference design (AR 1)	Preferred design
Width	40mm	40~50mm
Length	290mm	290~360mm
Height	260mm	213~240mm
Shape	Linear	Curved
Angle	Fixed	Adjustable
Material	Hard	Soft

3.2 Evaluation method of new bus seat armrest design

3.2.1 Participants

To verify the effects of the new bus seat armrest designs on satisfaction, 10 men and women (male: 9, female: 1) were recruited by applying the same recruitment criteria employed in the usability evaluation stage. The height (170.2 ± 7.7cm), seated elbow height (263 ± 17mm), and weight (70.8 ± 9.0kg) of the participants were found similar in terms of mean and variance with the height (165.4 ± 8.8cm; t[4546] = 1.71, p = 0.09; F[4537, 9] = 0.71, p = 0.176), seated elbow height (258.5 ± 24.3mm; t[4546] = 0.59, p = 0.56; F[4537, 9] = 1.15, p = 0.55), and weight (64.5 ± 12.1kg; t[4546] = 1.64, p = 0.10; F[4537, 9] = 0.55, p = 0.06) of the group of 20~50 years old Korean males and females (n = 4538) reported in the 2010 Size Korea anthropometric survey (KATS, 2010).

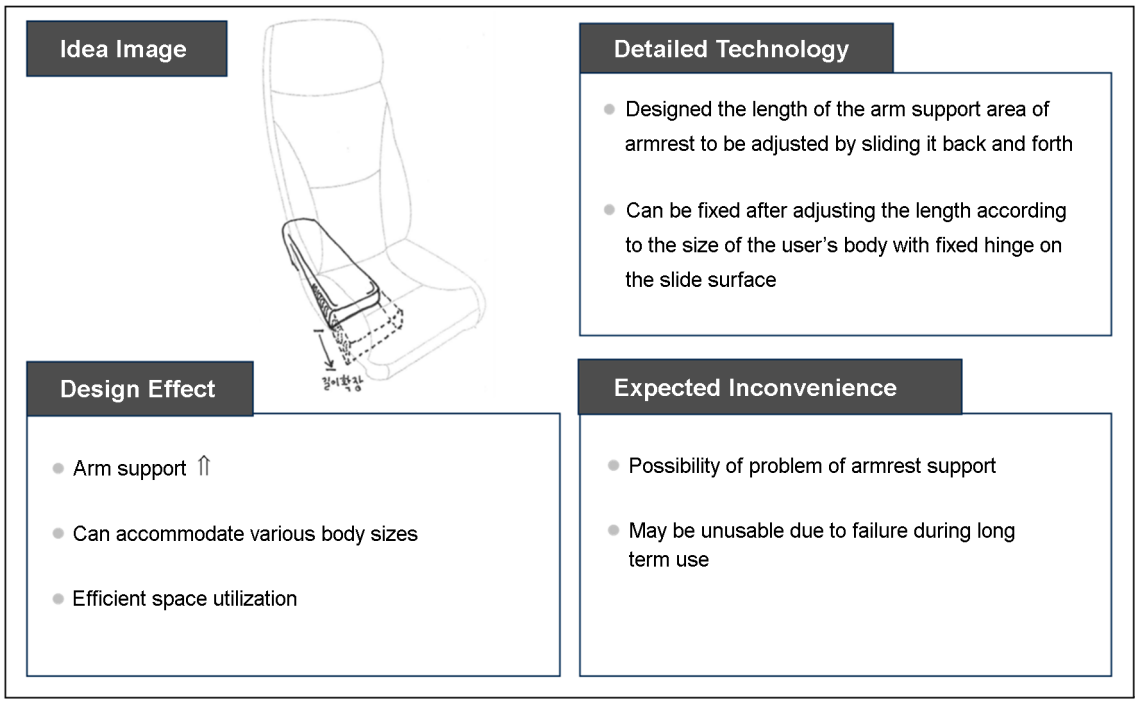

Figure 10. Example of idea development for bus seat armrest

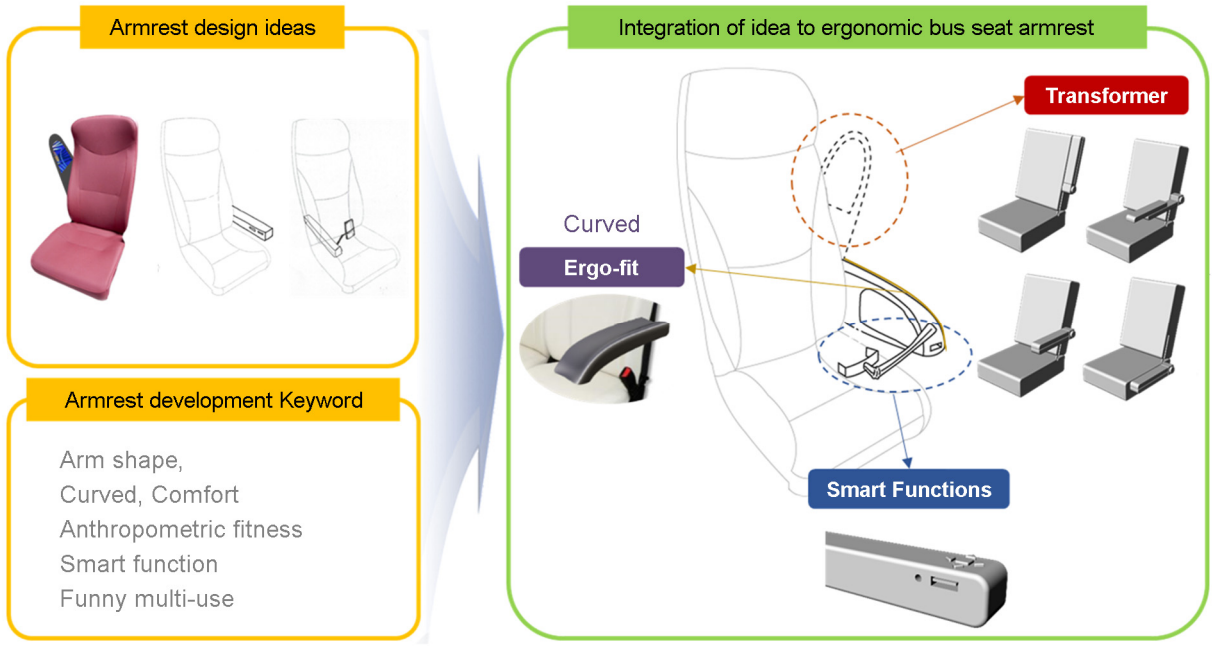

Figure 11. Idea integration for bus seat armrest improvement

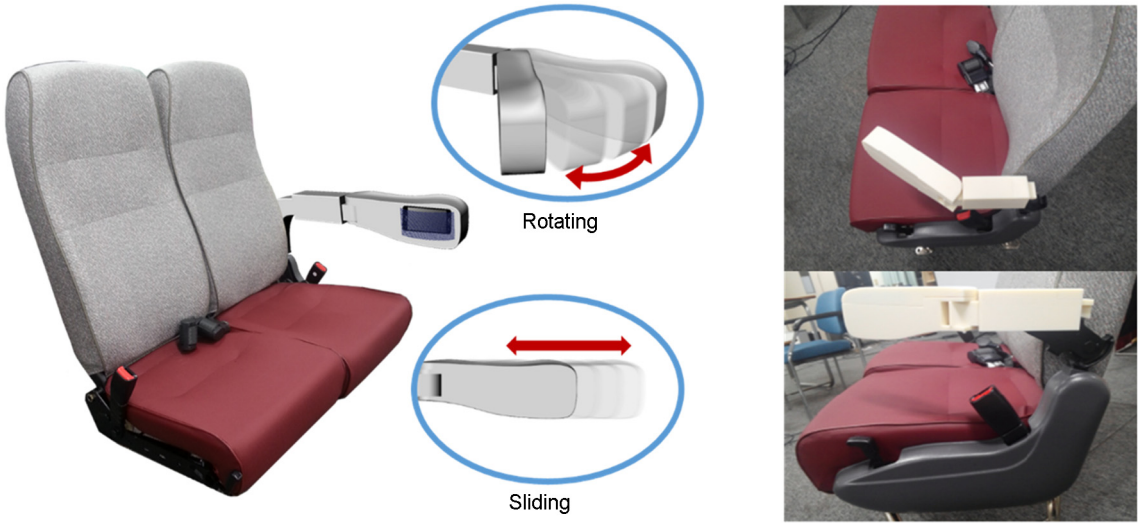

Figure 12. Structure and prototype of a new bus seat armrest design

Table 4. Design characteristics and specification of sliding-and-rotating (SRA) armrest

Design characteristics	SRA-flat	SRA-convex	SRA-concave
Shape	Linear	Curved	Curved
Side view			
Lateral curvature	–	704mm	586mm
Front view			
Frontal curvature	–	146mm	141mm
Length	290~360mm (Length adjustable)		
Width	50mm		
Height from seatpan	213mm		

3.2.2 Armrest designs

The three new armrests (SRA-Convex, SRA-Flat, and SRA-Concave) and one reference armrest (AR 1) were evaluated for validation. AR 1 was selected as the reference for comparison with the new armrest designs because its usability evaluation was found medium among the existing armrest designs.

3.2.3 Evaluation protocol

The satisfaction evaluation of the new armrests was performed using a 7-point scale (1: very dissatisfied, 4: neutral, 7: very satisfied) for the biomechanical and usability aspects considered in the armrest evaluation. The evaluation criteria of bus armrest included

length suitability, width suitability, angle suitability, contact area suitability, height suitability, comfort, and overall satisfaction. A questionnaire to record usability evaluation scores and comments on armrest designs was prepared as shown in Figure 13.

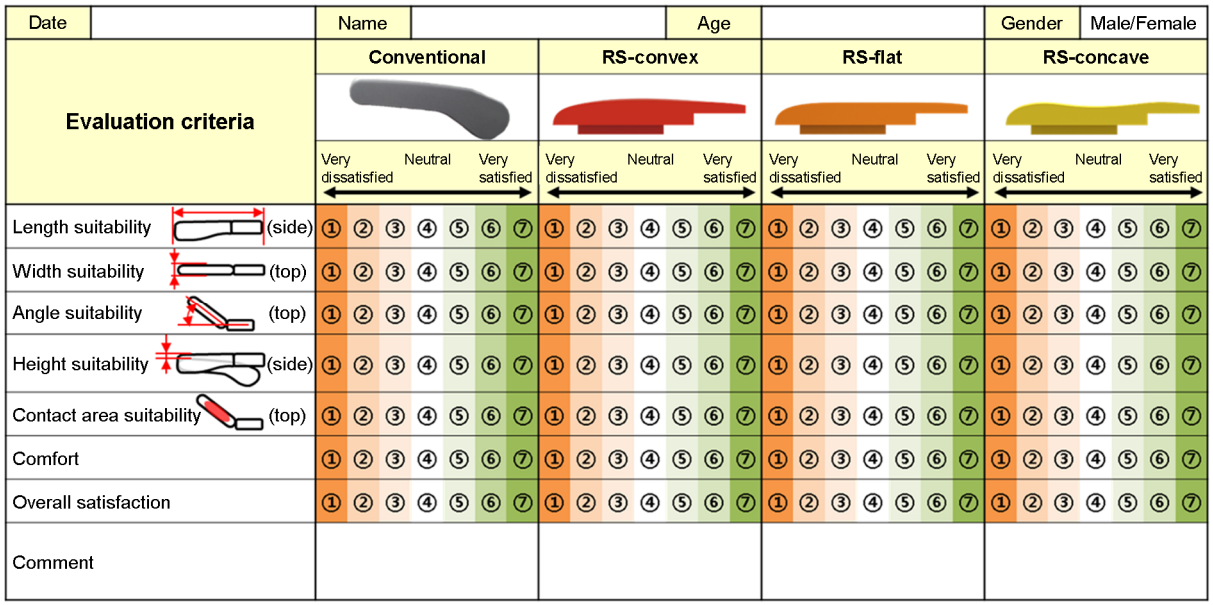

Figure 13. Subjective evaluation questionnaire for validation of new bus seat armrest designs

3.3 Evaluation results of new bus seat armrest design

The SRA-Convex, SRA-Flat and SRA-Concave designs were found significantly improved in all the satisfaction criteria compared to the reference armrest (AR 1). The SRA-Convex armrest design was rated most satisfactory (mean satisfaction = 6.3) in terms of length suitability, which was 62% higher in satisfaction than the reference armrest (mean satisfaction = 3.9) (F[3, 36] = 6.0, p = 0.002). Also the improved armrest designs were found preferred in terms of length suitability in the order of SRA-Convex (6.3), SRA-Flat (6.1), and SRA-Concave (5.7). Next, the SRA-Flat armrest was rated most satisfactory in terms of width suitability (mean satisfaction = 6.0; F[3, 36] = 48.2, p < 0.001), angle suitability (mean = 6.6; F[3, 36] = 61.9, p < 0.001), contact area suitability (mean = 5.9; F[3, 36] = 22.3, p < 0.001), height suitability (mean = 5.4; F[3, 36] = 8.3, p < 0.001), comfort (mean = 5.7; F[3, 36] = 25.0, p < 0.001), and overall satisfaction (mean = 5.9; F[3, 36] = 22.9, p < 0.001). The SRA-Flat armrest was improved by 216% in width suitability, 214% in angle suitability, 181% in contact area suitability, 64% in height suitability, 171% in comfort, and 111% in overall satisfaction compared to the reference armrest. Lastly, the SRA-Flat design showed the highest level of satisfaction (mean difference = 4.1~4.5) in all the evaluation criteria by 214% in angle suitability and 216% in width suitability when compared to the reference armrest (Figure 14).

4. Discussion

The present study analyzed the preferred design characteristics of bus seat armrest by evaluating bus seat armrests in various shapes and sizes for better usability. Existing studies conducted objective evaluations such as arm muscle load (EMG), seating pressure distribution, and postural stability to identify the effects of use of armrests in office chairs (Vos et al., 2006; Hasegawa and Kumashiro, 1998; Nag et al., 2008; Nag et al., 2013). However, research which examines the preferred design features of armrest

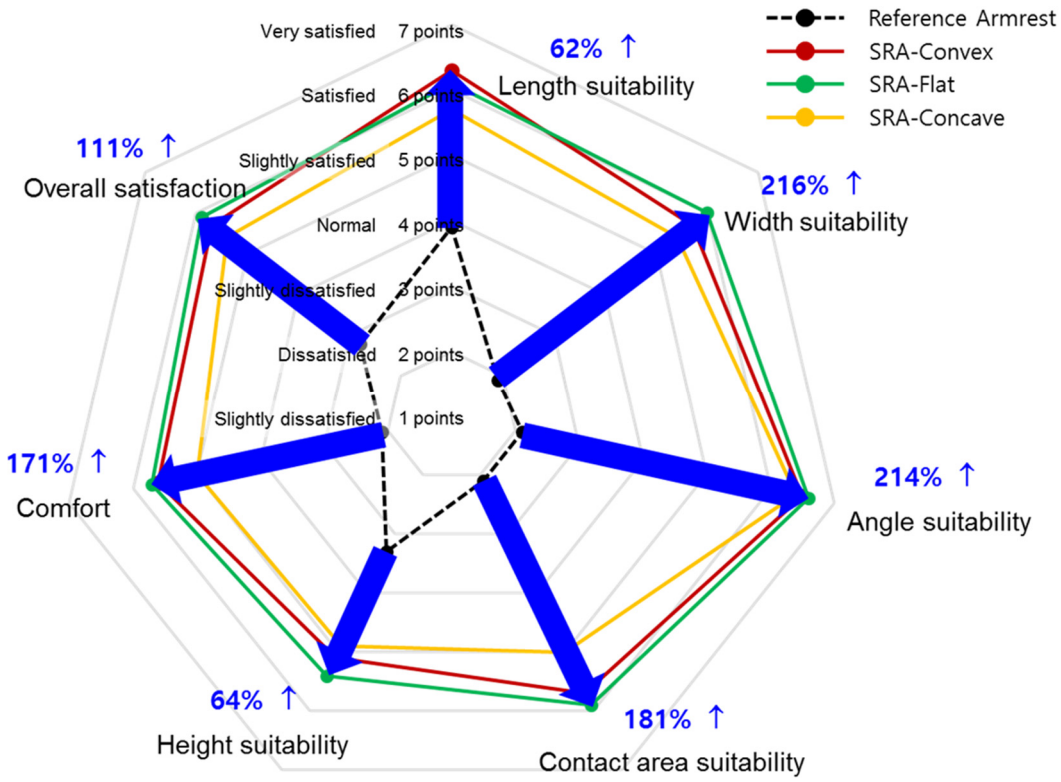

Figure 14. Satisfaction evaluation results of new bus seat armrest designs (SRA-Convex, SRA-Flat, and SRA-Concave) compare to the reference bus seat armrest

has not been reported for armrests of bus passenger seat. The present study evaluated bus seat armrest designs in terms of various satisfaction aspects including length suitability, width suitability, height suitability, form conformity, and overall satisfaction. Furthermore, the existing research has analyzed only positional aspects of armrest such as the height of armrest and the distance between armrests (Bush and Hubbard, 2007; Delisle et al., 2006; Hasegawa and Kumashiro, 1998; Nag et al., 2008; Van Veen et al., 2014). On the other hand, the present study investigated the length, width, and cross sectional shape of armrest as well as the height of armrest. Lastly, the present study quantitatively analyzed preferences of various armrest design dimensions by analyzing the characteristics of seven armrests of bus passenger seat.

The present study identified that the length, width, height, and shape of armrest affected the usability of an armrest. The length suitability of armrest was increased by 40% for an armrest with a length of 360mm compared to those with a length of 255~260mm, the width suitability by 60% for an armrest with a width of 40~50mm compared to that with a width of 35mm, and the shape conformity of armrest by 30% for a curved armrest compared to a straight armrest. The preferred armrest design features identified could be resulted from better accommodation of anthropometric variability of passengers. The present study identified that the height suitability of armrest was increased by 20% for armrests with a height of 213~240mm compared to that of a height of 260mm, which could be corresponded to the findings reported by Hasegawa and Kumashiro (1998) that trapezius EMG decreased as the armrest height decreased as the armrest height decreased from 260mm to 240mm to 220mm and that reported by Nag et al. (2013) that the postural stability increased by 14% as the armrest height increased from 170mm to 200mm and then to 230mm. On the other hand, Nag et al. (2008) reported that the weight distribution through the arms increased as the height of armrest increased from 215mm to 255mm and then to 275mm, which might be in conflict with the preferred armrest height

range identified in this study.

The proposed three new bus seat armrest designs (SRA-Convex, SRA-Flat, and SRA-Concave) were found enhancing usability in various aspects compared to an existing bus seat armrest for their ergonomically determined size, shape, and structure based on the armrest preference design characteristics, user requirements, and armrest design ideas. The existing bus seat armrest designs have limited adjustability capabilities in length and angle, causing an unnatural sitting posture and a limited accommodation of passengers in various body sizes such as arm length and elbow height. On the other hand, the proposed armrests were found more easily accommodating passengers in various body sizes and seating postures compared to the existing armrest designs by providing a top surface shape fit to the lower arm shape and a sliding and rotating structure for adjustment of length and angle. The new armrest designs improved satisfaction by 56% for length suitability, 216% for width suitability, 214% for angle suitability, 181% for contact area suitability, 63% for height suitability, 171% for comfort feeling, and 111% for overall satisfaction. The shape and structure of the new bus passenger seat armrest developed in the study was registered as a domestic patent (Kim et al., 2014).

The present study employed the evaluation method of satisfaction specialized toward bus seat armrest and 3D printing prototypes for validation of proposed armrest designs. Previous studies evaluated the usability of armrest mainly for office chairs, not for bus passenger seats. This study reproduced the bus passenger seat evaluation environment similar to the actual bus by referring to the seating comfort evaluation method of Park et al. (2015) and performed an effective usability satisfaction evaluation by applying subjective satisfaction evaluation criteria specific to armrest. Rapid prototypes were fabricated using a 3D printer to identify the effects of the proposed designs on armrest satisfaction. Although 3D printing prototypes were used effectively to verify the design effects of bus passenger armrests, the structural features of armrests by applying the finite element modeling (FEM) technique need to be further considered for the safety and robustness of armrest in the context of bus operation.

Although the present study was to evaluate the subjective satisfaction of bus seat armrests, the present study has limitations for not employing objective assessment methods such as muscular load (EMG), seating pressure distribution, and postural stability. Kuijt-Evers et al. (2007) and Harih and Dolsak (2014) noted that the objective evaluation methods such as muscular load (EMG) and seating pressure distribution are useful to interpret physical aspects while they are not highly correlated with subjective satisfaction evaluation results. Therefore, it is necessary to conduct subjective satisfaction evaluation considering various aspects in a comprehensive manner to improve satisfaction for a bus seat armrest. On the other hand, using a bus seat armrest, the sitting posture, postural stability, weight distribution, and muscular load are measured, the physical load of passenger can be quantitatively analyzed and armrest design characteristics minimizing the physical load of passenger can be applied to ergonomic design of armrest. Lastly, the sample size (n = 10) of participants in the validation study for the proposed armrest designs needs to be enlarged for better generalizability of the validation results.

The improved armrests developed in this study have a similar size to that of Korean wrists, allowing users of various sizes to be accommodated and improving user's satisfaction related to armrest width. The average wrist width of Korean from the 2010 Size Korea anthropometric survey (KATS, 2010) was 58.4mm (50.6mm for 5^{th} %ile, 58.5mm for 50^{th} %ile, and 65.3mm for 95^{th} %ile) and the maximum (50mm) of the armrest width range (35~50mm) was found similar to the average Korean wrist width and was applied to the improved armrest design. The new armrests improved by 216% for width suitability and by 181% for contact area suitability compared to the existing armrest. However, to identify an optimal armrest width, the width of the actual arm contact surface when using an armrest could be of use. Lastly, although the shape of the bus passenger seat armrest developed in this study was designed by considering the shape of the lower arm in sitting posture, a more systematic, in-depth human shape analysis is needed in the future.

Finally, to develop a bus seat armrest with improved seat comfort and reduced physical load, it is necessary to examine the

development of a bus seat armrest systematically considering the body shapes of passengers in 3D. The bus seat armrests based on the size and shape of the body can be manufactured in a similar shape to the human body contact area by measuring the passenger's posture and body size in sitting, and the armrest based on body shape is expected to reduce the physical load such as sitting pressure and muscle load by improvement of shape conformity and pressure distribution suitability (Mahmoudi and Bazrafshan, 2013). In addition, armrest design methods based on the shape and size of the human body need to be developed and human body data of various populations such as Koreans, Chineses, and North Americans need to be applied to designing an armrest so that the armrest design can be customized to various body shapes of ethnic groups, which can improve user satisfaction and product competitiveness.

Acknowledgements

This work was jointly supported by Hyundai-Kia Motor Company, the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science, and Technology under Mid-career Research Program (NRF-2015R1A2A2A03005486), and the Ministry of Trade, Industry, and Energy under Industrial Technology Innovation Program (No. 10063384).

References

Bush, T.R. and Hubbard, R.P., Support force measures of midsized men in seated positions, *Journal of Biomechanical Engineering,* 129(1), 58-65, 2007.

Delisle, A., Lariviere, C., Plamondon, A. and Imbeau, D., Comparison of three computer office workstations offering forearm support: impact on upper limb posture and muscle activation, *Ergonomics*, 49(2), 139-160, 2006.

Fredericks, T.K., Butt, S.E., Kumar, A.R., Amin, S.G., Utkan, F. and Belingar, T., Influence of armrest width and task on armrest usage, *In Proceedings of IIE Annual Conference and Expo 2014*, 2326-2335, 2014.

Groenesteijin, L., Ellegast, R.P., Keller, K., Krause, F., Berger, H. and de Loose, M.P., Office task effects on comfort and body dynamics in five dynamic office chairs, *Applied Ergonomics*, 43(2), 320-328, 2012.

Harih, G. and Dolsak, B., Comparison of subjective comfort ratings between anatomically shaped and cylindrical handles, *Applied Ergonomics*, 45(4), 943-954, 2014.

Hasegawa, T. and Kumashiro, M., Effects of Armrests on Workload with Ten-key Operation, Applied Human Science: Journal of Physiological Anthropology, 17(4), 123-129, 1998.

Kim, J., Na, H., Cho, D., Shin, Y., Park, S. and Kim, J., Development of questionnaire for automobile seat comfort evaluation, *Korean Journal of the Science of Emotion and Sensibility*, 13(2), 381-390, 2010.

Kim, M., Choi, Y. and You, H., The arm rest of a seat. *Patent Application Number: 10-2014-0152184*, 2014.

Kolich, M., Automobile seat comfort: occupant preferences vs. anthropometric accommodation, *Applied Ergonomics*, 34, 177-184, 2003.

Korean Agency for Technology and Standards (KATS), 2010. *The Report on the 6th Size Korea (Korean Body Measurement and Investigation)*, Seoul, Korea: Size Korea, Ministry of Knowledge Economy

Kuijt-Evers, L.F.M., Vink, P. and de Looze, M.P., Comfort predictors for different kinds of hand tools: Differences and Similarities, *International Journal of Industrial Ergonomics*, 37, 73-84, 2007.

Lee, W., Jeong, J., Park, J., Jeon, E., Kim, H., Jung, D., Park, S. and You, H., Analysis of the facial measurements of Korean Air Force pilot for oxygen mask design, *Ergonomics*, 56, 1451-1464, 2013.

Mahmoudi, N. and Bazrafshan, M., A Carpet-Weaver's Chair Based on Anthropometric Data, *International Journal of Occupational Safety and Ergonomics*, 19(4), 543-550, 2013.

McCormick, D.A. and Tubergen, R.G., System to Monitor Task Chair Seating, *Clinical Biomechanics*, 18(10), 981-984, 2003.

Nag, P.K., Pal, S., Kotadiya, S.M. and Gosai, N.K., Human-seat interface analysis of upper and lower body weight distribution, *International Journal of Industrial Ergonomics*, 38(5-6), 539-545, 2008.

Nag, P.K., Vyas, H., Nag, A. and Pal, S., Postural Stability of Sitting Women, *International Journal of Occupational Safety and Ergonomics*, 19(4), 583-595, 2013.

Park, J., Lee, H., Choi, Y., Park, K., Kim, M. and You, H., Development of an Evaluation Protocol for a Bus Seat, *Journal of the Korean Institute of Industrial Engineers*, 41(1), 74-78, 2015.

Smith, D.R., Andrews, D.M. and Wawrow, P.T., Development and evaluation of the Automotive Seating Discomfort Questionnaire (ASDQ), *International Journal of Industrial Ergonomics*, 36, 141-149, 2006.

Son, H., Jeong, B. and Sin, M., Safety Armrest Bar for Skid Steer Loader, *Patent Registered Number: 30-2014-0044239*, 2015.

Van Veen, S.A.T., Van Mastrigt, S.H., Kamp, I. and Vink, P., Improving car passengers' comfort and experience by supporting the use of handheld devices, *Work*, 49(2), 215-223, 2014.

Vos, G.A., Congleton, J.J., Moore, J.S., Amendola, A.A. and Ringer, L., Postural versus chair design impacts upon interface pressure, *Applied Ergonomics*, 37(5), 619-628, 2006.

Zhao, J. and Tang, L., An evaluation of comfort of a bus seat, *Applied Ergonomics*, 25(6), 386-392, 1994.

Author listings

Hayoung Jung: niceterran36@postech.ac.kr
Highest degree: MS, Department of Industrial and Management Engineering, Pohang University of Science and Technology
Position title: Ph.D. Candidate, Department of Industrial and Management Engineering, Pohang University of Science and Technology
Areas of interest: Ergonomic Product Design & Development, Industrial Design, Human Computer Interface & User Experience Design Engineering

Seunghoon Lee: shooonlee@postech.ac.kr
Highest degree: MS, Mechanical Engineering, Sogang University

Position title: Ph.D. Candidate, Department of Industrial and Management Engineering, Pohang University of Science and Technology
Areas of interest: Digital human modeling & simulation, User-centered product design & development, Anthropometric and biomechanical methods for product development, Human performance & workload assessment

Moonjin Kim: moonjin@hyundai.com
Highest degree: BS, Mechanical Engineering, Chonbuk National University
Position title: Part manager, Bus Body Engineering Team, Hyundai Motor Group
Areas of interest: Automotive seating development & design, Virtual seat prototyping, Ergonomic product design & development, User behavior pattern analysis

Hoimin Choi: HMChoi@hundai.com
Highest degree: BS, Mechanical Engineering, Chonbuk National University
Position title: Research engineer, Bus Body Engineering Team, Hyundai Motor Group
Areas of interest: Automotive seating development & design, Virtual seat prototyping, Ergonomic product design & development, User behavior pattern analysis

Heecheon You: hcyou@postech.ac.kr
Highest degree: Ph.D., Industrial Engineering, Pennsylvania State University
Position title: Professor, Department of Industrial and Management Engineering, POSTECH
Areas of interest: Ergonomic product design & development, User interface design & evaluation, Digital human modeling & simulation, Human performance & workload assessment, Usability testing. Temporal 3-D scanning