A STUDY OF INFLUENCE FACTORS OF HEAD RESTRAINTS ON NECK INJURIES

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ABSTRACT

Neck Injuries, referred to in this paper as whiplash are among the most frequent injury among occupants in low speed rear end car collision. This paper analyzes the correlations between influence parameters of head restraints and whiplash injury criteria. In this paper, we used DFSS (Design for Six Sigma) method for design optimization of head restrains. Four control factors of head restraints have been selected by function matrix method. The effects of the control factors have been experimentally evaluated by using a sled pulse from 16kph relative velocity which is suggested by Korean New Car Assessment Program (KNCAP). Whiplash tests were repeated once in order to reduce the noise factors of dynamic assessments. By using DFSS, the correlation between control factors of head restraints and injury criteria has been comprehended.

INTRODUCTION

Out of the population of occupants that experienced any kind of injury in rear impacts, most experienced whiplash, which is considered a minor injury as classified by the Abbreviated Injury Scale (AIS,moderate) 2 or less[1]. Whiplash Associated Disorders (WAD) are usually caused by the motion of the head and neck complex relative to the torso. Occupants can suffer headaches and neck pain for a few days or weeks.[2] Many researchers have been studying to establish the cause of whiplash injury. Some of them focusing on anatomical sites such as facet joints, spinal ligaments, intervertebral discs, vertebral arteries, dorsal root ganglia, and neck muscles-within the neck that are potentially injured during rear-end collisions.[3] However, the injury mechanism of symptoms associated with whiplash is not well understood. Various whiplash injury criteria have been proposed, criteria developed by the Insurance Whiplash Prevention Group (IIPG), which is comprised of various insurance industry supported research groups from around the world. For these reasons, New Car Assessment Program (NCAP) is carrying out whiplash testing using the BioRIDIIg dummy. According to an automobile insurance statistics report of Korea Insurance Development Institute (KIDI) in 2005, the number of people injured in rear end impact collisions was approximately 53,000. Of these, 33,000 people reperted neck injuries as the most significant injury. Also, insurance companies in Korea paid premiums of approximately 180 billion KRW(166 million USD) in connection with whiplash related injuries.[4] This paper aims to analyze the correlation between influence parameters of head restraints and whiplash injury criteria. Occupant comfort and visibility are also to be considered when optinizing head restrraints. However, for this paper, we only focused on improving whiplash rating, without regard to the comfort and visibility aspects. In this paper, Design for Six Sigma (DFSS) methods [5] and sled tests are used for design optimization of head restraints, prioritizing on whiplash performance.

ROBUST DESIGN

		Injury Criteria						
		NIC		Nkm		Head Rebound Vel.	Upper Neck Fz	Head Contact Time
		Head X Acc.	T1 X Acc.	Neck Fx	Neck My			
H/R	Form depth				+	++		
	Form Hardness				+			
	Form Elastic				+	+		
	Backset	+			+			++
	Height				+		++	
	4way/2way							+
	Angle of Head Contact Area				++		+	
	Mold	+		+				

Figure1. Function matrix

Head restraints have many design elements including foam depth, foam hardness, foam elastic, backset and height for occupant safety. Of these, we choose control factors and output responses using neck injury criteria which have been proposed by Korea Automobile Testing & Research Institute (KATRI).Figure 1 shows a function matrix to select the control factors of head restraint. We selected foam depth, backset, height, angle of head restraints as control factors.

Table.1
Control factor and parameter level

No.	Control factor	Level 1	Level 2	Level 3
A	Foam Depth	-10mm	Normal	10mm
B	Backset	-10mm	Normal	10mm
C	Height	-10mm	Normal	10mm
D	H/R angle	-10°	Normal	10°

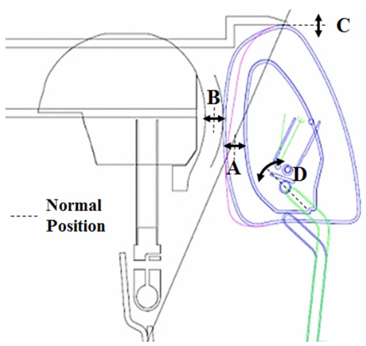


Figure2. Definition of setting the control factors

Control factor and parameter level is shown in Table1. Normal of level 2 means initial manufactures current design position. Definition of setting the control factors is shown in Figure2. Seat tolerance, sled acceleration pulse and dummy positioning are chosen as noise factors. Figure 3 shows P-diagram.

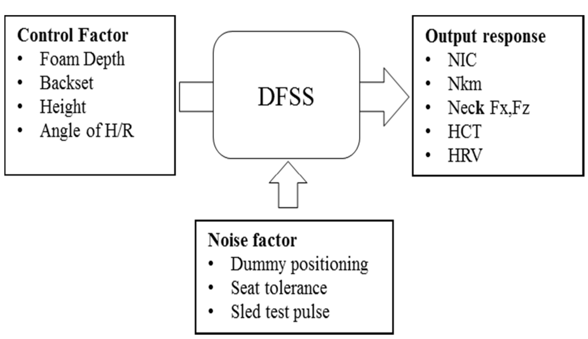


*Figure3***.** P-diagram

Orthogonal array

Orthogonal matrix was composed to determine the main effects of control factors. In general, there are no interaction effects between control factors in mechanical systems. The interaction effect between control factors was not considered. Control factors and level in L_9 orthogonal array is shown in Table 2 and Figure 4.

Table. 2
L9 orthogonal array

Run	Foam Depth	H/R Angle	Backset	Height
1	-10mm	-10º	-10mm	-10mm
2	-10mm	Normal	Normal	Normal
3	-10mm	+10º	+10mm	+10mm
4	Normal	+10º	-10mm	Normal
5	Normal	-10º	Normal	+10mm
6	Normal	Normal	+10mm	-10mm
7	+10mm	Normal	-10mm	+10mm
8	+10mm	+10º	Normal	-10mm
9	+10mm	-10º	+10mm	Normal

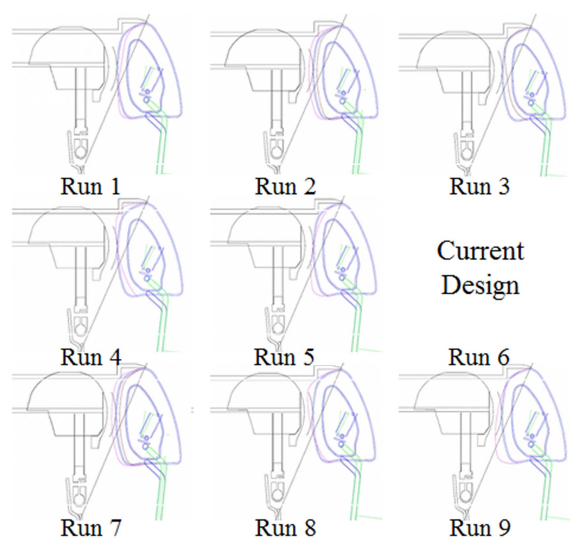


Figure4. Combination of control factors in L9 orthogonal array

Sled test

The main effects of the control factors were evaluated by sled testing. The sled testing conducted only dynamic assessment. Fig 5 shows dummy positioning of dynamic assessment. BioRIDIIg was positioned in the two-way front seat jig and two-way head restraints. We conducted series of sled tests by using 16kph delta V rear impact acceleration pulse that is representative of KNCAP triangle pulse of whiplash test. The acceleration pulse generated in this sled is shown in Figure 6. Each sled test was repeated once in order to reduce the influence of noise factors from difference of sled test NIC, Nkm, NeckFx Neck Fz, Head Contact Time (HCT) and Head Rebound Velocity (HRV) were measured as injury criteria of dummy.

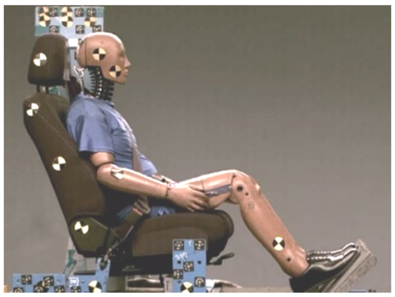


Figure5. Dummy positioning for dynamic assessment

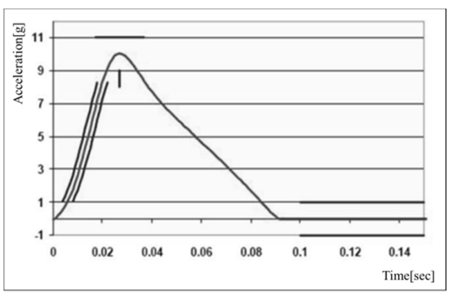
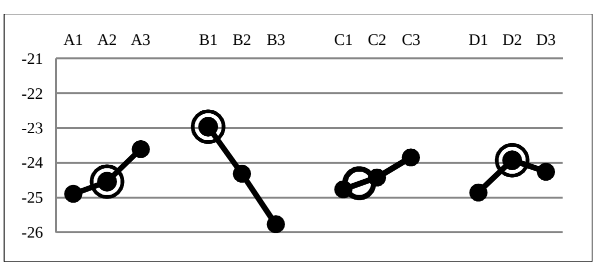


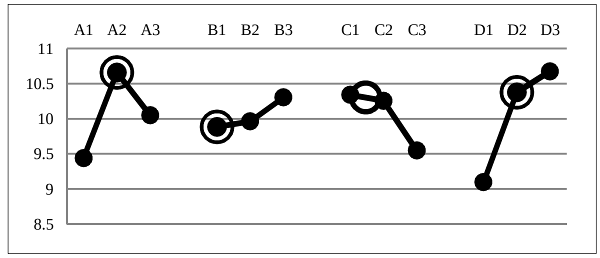
Figure6. Sled Target acceleration pulse

Analysis of signal to noise

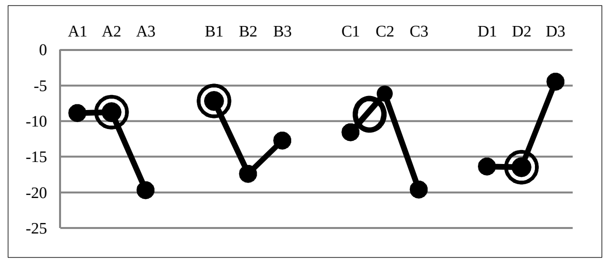
The response plot for (a) NIC, (b) Nkm, (c) Neck Fx, (d) Neck F3z, (e) Head Contact time and (f) Head rebound velocity are shown in figure 7. Horizontal axis is control factors and parameter level. Circle indicates optimal combination of each parameter level for each control factor in response graph.



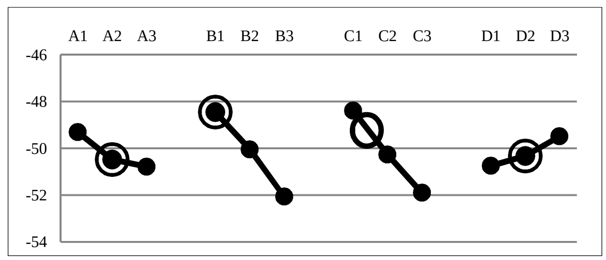
(a) NIC



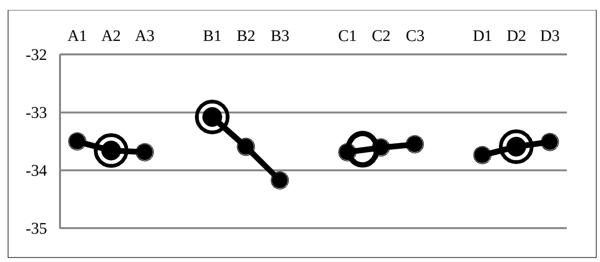
(b) Nkm



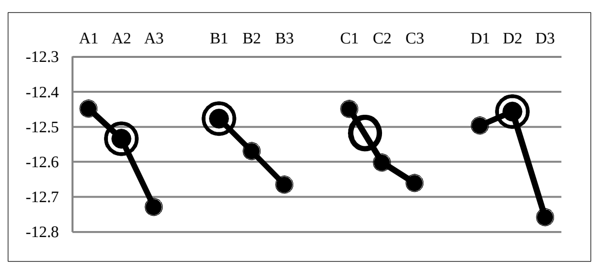
(c) Neck Fx



(d) Neck Fz



(e) Head Contact Time



(f) Head Rebound Velocity

Figure7. Response plot between control factor and parameter levels

Table.3
P-value and contribution of control factors

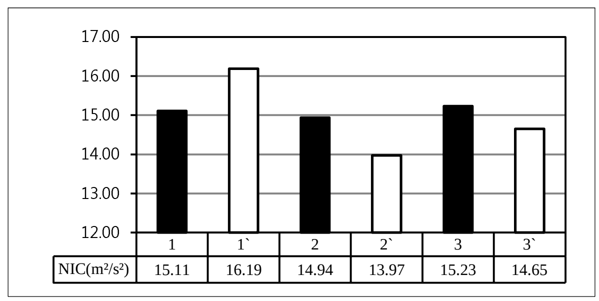
Output Response	Control factor	P-value	Percent Contribution
Nkm	Foam Depth	0.084	19
	Backset	0.576	3
	Height	0.259	9
	H/R Angle	0.014	42
NIC	Foam Depth	0.037	11
	Backset	0	67
	Height	0.145	6
	H/R Angle	0.152	6
Neck Fz	Foam Depth	0.249	5
	Backset	0.005	35
	Height	0.004	38
	H/R Angle	0.17	7
Neck Fx	Foam Depth	0.342	15
	Backset	0.708	4
	Height	0.321	16
	H/R Angle	0.543	8
Head Rebound Velocity	Foam Depth	0.065	22
	Backset	0.245	10
	Height	0.171	13
	H/R Angle	0.034	29
Head Contact Time	Foam Depth	0.213	3
	Backset	0	84
	Height	0.473	1
	H/R Angle	0.151	4

Table 3 shows the result of the significance percent contribution of each control factor through the analysis of variance on the output responses. ANOVA can determine influence of control factors from a series of sled test results by using design of experiment.[5] Percent contribution is based on the estimates of the variance components. Also, the percentage contribution of each factor can be used to evaluate the importance of the factor on the performance characteristic. The reliable correlation factors were satisfied with 5% significance level and contribution limit over 20%. NIC has 67% contribution and zero p value with regard to backset. Nkm has 42% contribution and 0.014 of p value with regard to head restraints angle. Neck Fz has 35% contribution and 0.005 of p value with regard to backset. It has 38% contribution and 0.004 of p value with regard to height. Neck Fx has more than 0.05 of p value with regard to all of control factors. Head rebound velocity has 0.034 of p value with regard to head restraints angle. Head contact time has 84% contribution and zero p value with regard to backset. In this paper, we selected correlation factor based on two way analysis which are significance level and percent contribution limit. As a result, Nkm had a significant correlation to head restraints angle. And Neck Fz had a correlation to backset and height. Head rebound velocity had a correlation to head restraints angle. Finally, Head contact time showed a correlation to backset. Table 4 shows optimal combination of control factor and parameter level.

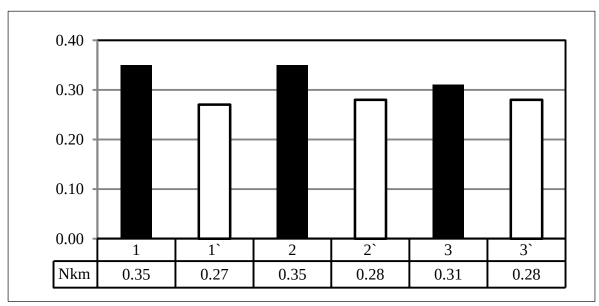
Table.4
Optimal combination of control factors

Control factor	Baseline	Opt. 1	Opt. 2
Foam Depth	Normal	Normal	Normal
Backset	Normal	-10mm	-10mm
Height	Normal	Normal	-10mm
H/R Angle	Normal	Normal	Normal

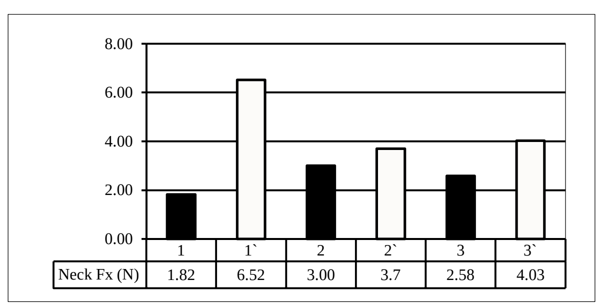
RESULT



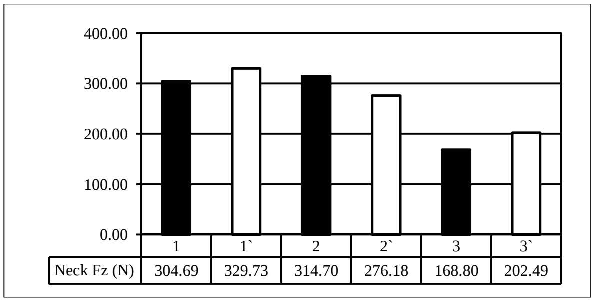
(a) NIC



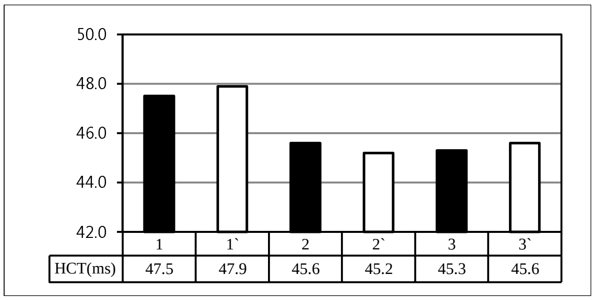
(b) Nkm



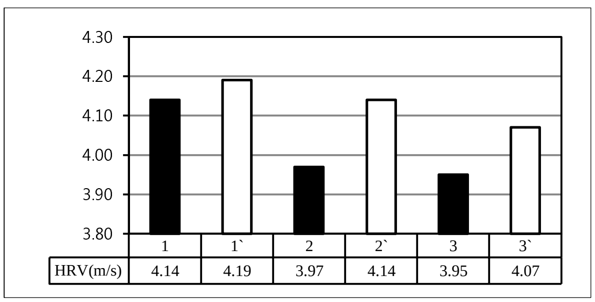
(c) Neck Fx



(d) Neck Fz



(e) Head contact time



(f) Head rebound velocity

Figure8. Comparison of predicted value and verification value

Figure8 shows comparison of dummy injury in the predicted versus verification value of sled tests. Black bar shows actual sled test value and white bar shows predicted value of control factors. Arabica numerals on the horizontal axis indicate value of baseline (1/1'), Opt.1 (2/2') and Opt.2 (3/3'). In this paper, we judged that the valid control factors were subject to correspond the tendency of output characteristic in S/N ratio response graph and to confirm the difference between predicted values and actual sled test values within 30%. As a result, the output response of the S/N ratio and the ANOVA analysis for control factors shows a very strong influence of selected (b) Nkm, (d) Neck Fz, (e) HCT and (f) HRV and no or little influence of (a) NIC, (c) Neck Fx. Nkm was decreased by reward tilting angle of head restraints. And, Neck Fz was decreased by decreasing backset and increasing height. HCT was reduced by decreasing backset. And HRV decrease by forward tilting angle of head restraints.

Table 5 Prediction and Actual sled score

Parameters	Baseline	Opt. 1	Opt. 2
Prediction Score	7.0	7.3	7.3
Actual Score	6.9	7.1	7.2

Table 5 shows comparison of prediction score and actual score of sled testing. KNCAP whiplash assessment is composed of seven criterias - head restraints contact time, T1 x-acceleration, upper neck shear force, upper neck tension, head rebound velocity, NIC, Nkm. Test total score is maximum 9 point. We have improved result more than baseline. Also, Opt2. is highest score. It means DFSS has been applied effectively.

CONCLUSION

DFSS principals were used In the analysis of influence factor of head restraints on the whiplash performance. As a result, Nkm was decreased by rearward tilting the angle of the head restraints. And, Neck Fz was decreased by decreasing backset and increasing height. HCT was reduced by decreasing backset. And HRV decreased by forward tilting angle of head restraints. We intend to apply this DFSS as a tool in parameter studies to analyze optimum seat characteristics for effective seat design considering the occupant safety.

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