SEAT DESIGNS FOR WHIPLASH INJURY LESSENING

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ABSTRACT

The purpose of this study is to evaluate the potential for the reduction of occupants neck injuries, so called "whiplash injuries" (whiplash associated disorder), in rear end collisions. Based upon new biomechanical research, an effort was made to design head restraints and seats to help lead to a reduction of such injuries. This resulted in a concept which involves the motion of the head and torso in harmony during a rear end collision. Consequently a newly designed seat based upon this concept is evaluated in low speed rear impact dummy sled tests, and additionally offered in volunteer sled tests using X-ray cinemas conducted by Japan Automobile Research Institute and University of Tsukuba, who investigate the influence of seat characteristics to human head and torso kinematics and cervical vertebra movement to reveal the mechanism of whiplash injuries. As a result, it was found that the motion between head and torso as well as the movement between each cervical vertebra was reduced.

INTRODUCTION

Whiplash injuries which occur mainly in rear end collisions are the most frequent injuries reported in traffic accidents. In Japan, approximately 40% (approximately 200 thousand occupants in struck vehicles per year) of all injuries are caused by rear end collisions [1], and approximately 80% of rear end collisions are neck injuries of varying severity [2]. Its by-product is a very high social and economic cost, for example $4.5 billion per year in the USA [3].

The majority of whiplash injuries result in no objective evidence such as X- rays, MRIs, or electric signals (EEG, EMG, SEP, etc). However subjectively they can present pain, numbness, headache, and so on. Furthermore, they can potentially lead to long term disability of which approximately 40% require more than one year treatment according to the investigation of Galasko et al. [4]. Therefore, it is understood that complicated circumstances are behind whiplash injuries.

Up to this time, head restraints have been thought to prevent whiplash injuries caused by hyper-extension of neck. However biomechanical studies in recent years, by Matsushita et al. [5], who investigated cervical spine movements in volunteer sled tests using X-ray cinemas, found that whiplash injuries could be caused within a normal range of neck motion. The same theory was reported by McConnell et al. [6].

At present there are several hypotheses explaining the mechanism of whiplash injuries. Svensson et al. [7] suggested that a swift motion of neck can cause nerve damage in a spinal ganglia of lower cervical regions due to the pressure changes experienced in pig tests. The same trauma was reported by Miyoshi [8] from rabbit pendulum tests using X-ray cinemas. Matsushita et al [5] concluded that discomfort symptoms are from micro-injuries of musculature or soft tissues caused by a passive stretching in resistence to inertial loads. Ono and Kaneoka [9], who investigated each cervical vertebra movement from volunteer sled tests using X-ray cinemas, suggested that an abnormal crash extension of C5/C6 could cause facet impingement injuries.

The Concept- Though the mechanism of whiplash injuries is not completely understood, a decrease in neck motion is thought to lessen whiplash injuries. Expressing the above ideas visually, Figure.1 shows the concept for reducing the likelihood of whiplash injuries or lessening the severity.

In 1982 Kahane [10] reported that the effectiveness of integral and adjustable head restraints, reducing neck injuries in rear end collisions, was 17 and 10 percent, respectively. Viano et al. [11] reported that from H-III dummy sled tests a 28.3% injury reduction in risk could be achieved by merely adjusting all head restraints to the extended position. By contrast, in 1996 NHTSA [3] questioned how, for example, head restraints and seating systems can be improved to reduce neck injuries.

This study attempts to present some solutions, for not only the head restraint but also the seat back. Yet other factors have much to do with whiplash injuries such as age, physique, gender of occupants, and medical diagnosis and treatment by doctors.

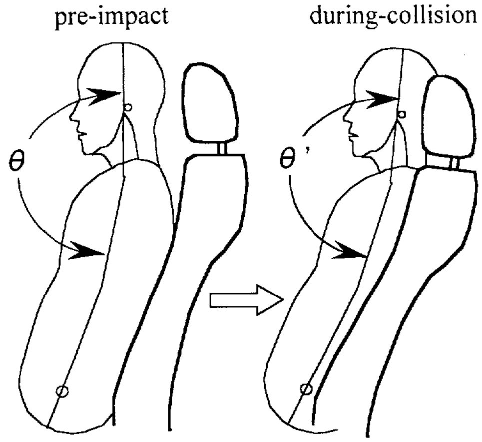

Figure 1. Desirable occupant motion during impact in low-speed rear end collision.

COMPLEMENT TO ACCIDENT DATA

Crash severity in which whiplash injuries occur is examined from the 1993 NASS data of rear end collisions involving AIS=1 neck injuries (Figure 2), Compared with the investigation by Eichberger et al. [12] of Graz University, NASS data is concentrated toward higher velocity change. This is because severe crash accidents are more frequently sampled than soft ones in the NASS data (samples over 50km/h are disregarded in this study).

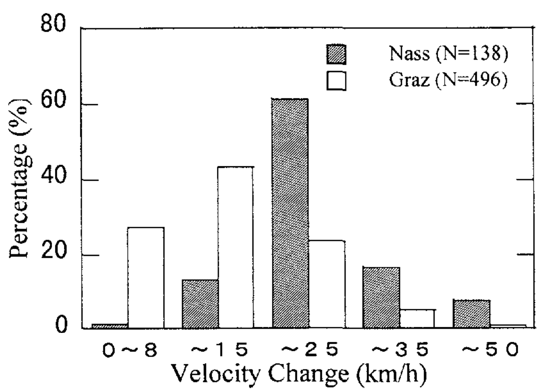

Figure 2. Distribution of velocity change (ΔV) of the struck car in rear end collisions involving whiplash injury.

Considering this data, it is clear that whiplash injuries occur most often in low speed collisions within 25 km/h of velocity change, so to evaluate whiplash injuries, low speed tests are suitable.

DESIGN CONCEPT

It is important to arrange the sitting posture of the occupant as straight up as possible, because a slouching posture will keep the occupant's head distant from the head restraint. The locus of adjusting the head restraint is designed to move almost vertically. This is because, when driving, the backs of head, depending upon the body size of the occupants, are located almost on the same vertical axis as shown in Figure 3 on the left, which represents the head of AM95, AM50, and AF05 from the top.

Geometry of The Head Restraint and Seat Back

First, for the low-speed rear end collisions, the head restraint, especially the metal frame, is moved forward and upward. But it has some limitations, because if the head restraint is too near the head it interferes with the occupant's head and causes discomfort while driving. Second, the upper part of the seat back frame is moved rearward away from the upper torso with the seat surface remaining to support the upper torso the same way as in the original seat design, and also raised along with the head restraint. During rear end collisions the upper torso mildly sinks into the seat back, and when the upper torso stops and starts to rebound, at the maximum deformation of the seat back, the head is restrained naturally by the head restraint (Figure 3). Therefore head and torso move in harmony, and head stops and starts to rebound simultaneously with the torso (less whiplash movement). The pelvic support at lower part of the seat back frame initiates the lower torso to rebound first, and therefore helps to prevent the neck extension motion through its relative flexion motion.

To position the head restraint as high as the top of the occupant's head is not quite necessary. The reason is because it is not the pad but the frame of the head restraint which sustains the occupant's head during rear end collisions. The head restraint height (H) of approximately 800mm parallel with the torso line is considered sufficient even for AM95 if the insert frame of the head restraint sustains the head center of gravity.

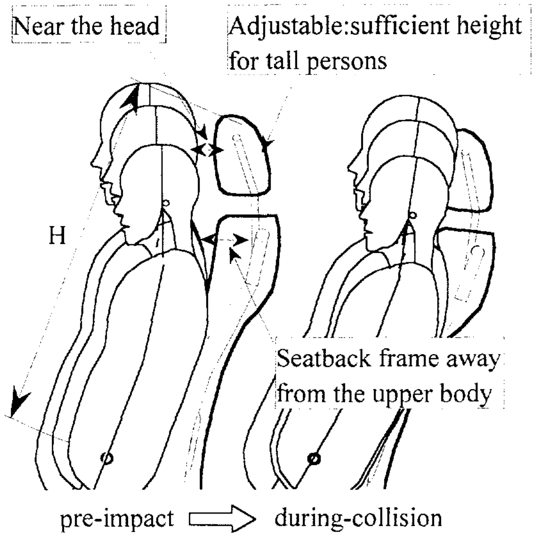

Figure 3. Geometry of the seat structure.

DUMMY SLED TESTS

Modified Dummy Neck

There is no doubt that H−Ⅲ original neck is too stiff to evaluate neck extension motion in low speed rear impact dummy sled tests simulating low-speed rear end collisions. So H−Ⅲ original neck is modified as shown in Figure 4 in order to achieve higher bio-fidelity, referring to TNO RID neck Ⅱ [13].

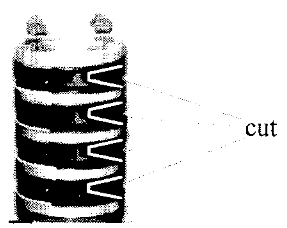

Figure 4. Modified H−Ⅲ neck.

Figure 5 shows performance of modified neck as compared with human necks. These tests were performed without head restraints. TNO's reference line [13] in Figure 5, represents the border between relaxed and tensed human before impact, determined by various volunteer and cadaver tests. Even if results are somewhat influenced by various seat performance, the modified neck roughly located on the border line. The stiffness difference between the modified neck and the original H−Ⅲ neck, also shown in Figure 5, is approximately 30%.

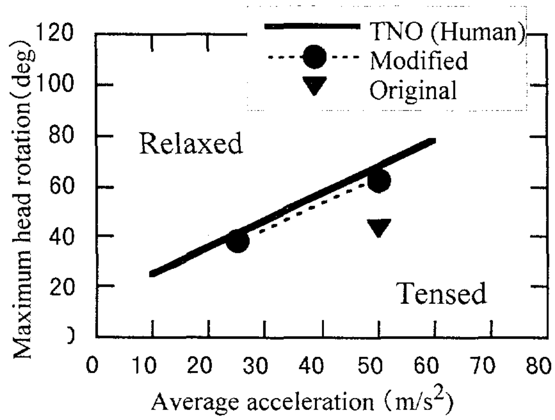

Figure 5. Maximum head rotation of modified and original H−Ⅲ neck compared with human.

Test Method

To evaluate the new seat design, low speed rear impact dummy sled tests were performed using AM50 H−Ⅲ dummy (Table 1).

Table 1.
Summary of Dummy Sled Tests

Test No.	Head-restraint	Velocity Change(km/h)	Neck
D01	Yes	8	Modified
D11	Yes	12.5	Modified

one sled pulse was derived from the acceleration pulse of car to car rear end collisions and resembles by the half sin-curve to be approximately 12.5 km/h velocity change. The other 8 km/h velocity change sled pulse was also derived from JARI's data of actual car rear end impact experiments.

In each test the dummy was positioned with Hip point determined by SAE mannequin, and a initial gap (a horizontal distance between head and head restraint) determined by human driving postures was set. The center of head restraint was adjusted to be level with the gravity center of the dummy head. The dummy was belted by normal 3- point belts. This sled needs initial velocity before impact, so two pieces of urethane pads were installed to support dummy's head and chest while accelerating to reach required initial velocity. Dummy accelerations were measured and dummy motions were filmed with a high speed video camera.

Results

In each test the dummy's pelvis, chest, lower head and upper head stop and start to rebound one after another. However, in spite of soft crash, each rebound time of D01 is slower than that of D11.

The dummy's resultant acceleration and motion data are time- historically shown in Figure 6 and Figure 7. Here the reference point is on the sled, and all numerical values are initially zero. As a fact, in D11 rearward head rotation angle is larger than that of D01 for the high velocity change, however Δθ max (maximum relative rotation angle between head and torso) of D11 is smaller than that of D01 because in D11 the rearward torso rotation is larger than in D01.

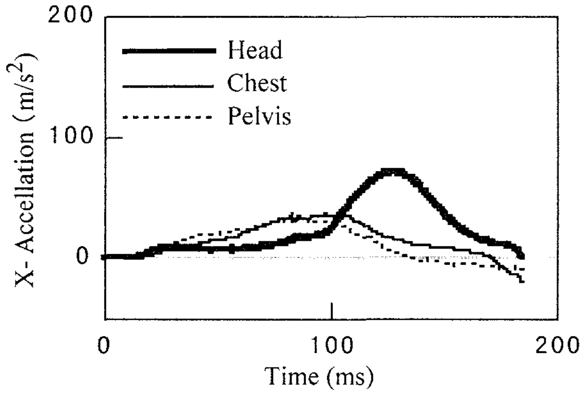

Figure 6A. ΔV= 8 dummy response (D01).

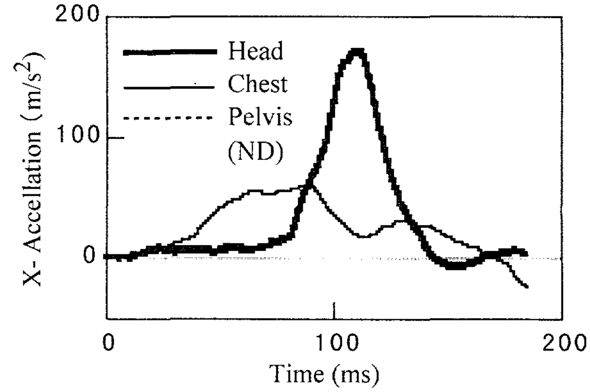

Figure 7A. ΔV= 12.5 dummy response (D11).

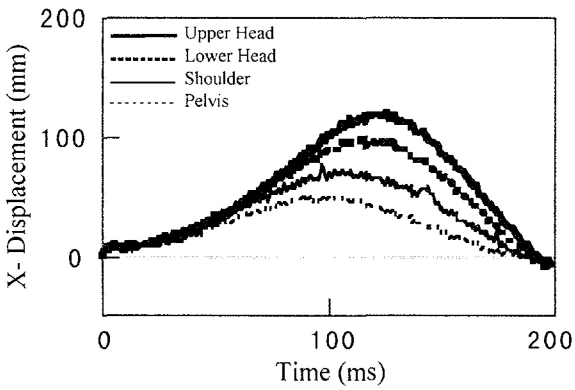

Figure 6B. ΔV= 8 dummy response (D01).

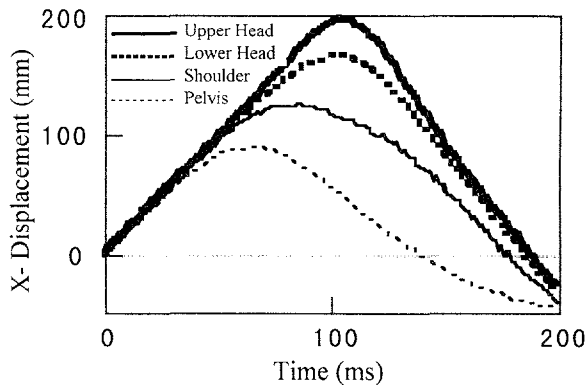

Figure 7B. ΔV= 12.5 dummy response (D11).

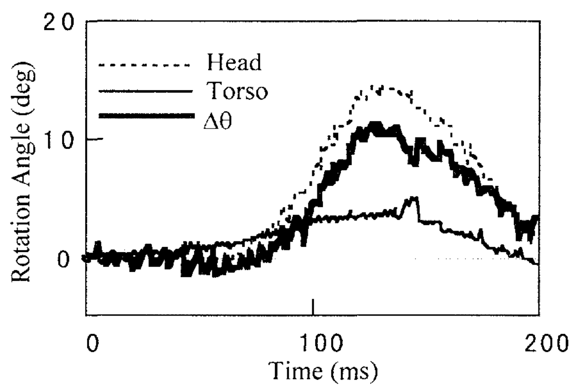

Figure 6C. ΔV= 8 dummy response (D01).

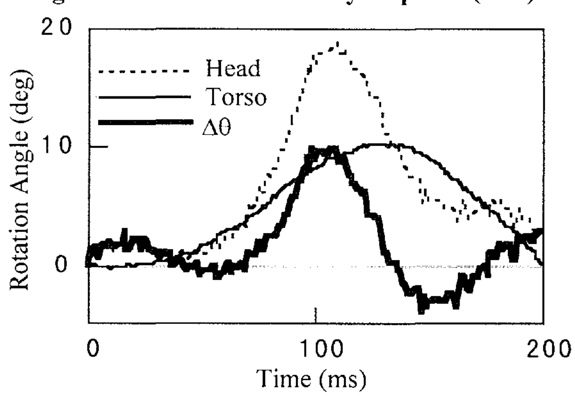

Figure 7C. ΔV= 12.5 dummy response (D11).

The rearward torso rotation is a flexion motion for the neck, and therefore able to cancel the rearward head rotation and lead to a reduction of $\Delta\theta$ max.

Eichberger et al. of Graz University [12] who also performed volunteer sled tests indicated that a $\Delta\theta$ exceeding 30 degrees caused cervical distortion and exceeding 15 degrees caused pain. Compared with this investigation, $\Delta\theta$ maxs of the newly designed seat are not high enough to cause pain, in both sled tests.

VOLUNTEER SLED TESTS

Human cervical vertebra movement cannot be simulated by the dummy. And consequently, volunteer sled tests using X-ray cinema was planed to observe cervical vertebra movement. JARI and University of Tsukuba have concentrated on the investigation of the influence of seat characteristics to human head and torso kinematics and cervical vertebra movement, after their examinations by volunteer sled tests [9], [14].

Table 2 shows a summary of these tests. The newly designed seat is also used and velocity change is 8 km/h. The seat position was identical to dummy sled test. The head restraint was adjusted so that the center was level to the ear center of the subject. Seat belts were not used. Test series V01, V02 evaluates volunteers' head and torso motion, and was performed at JARI. Test series V03, V04 evaluates cervical vertebra movement, and was conducted by JARI at University of Tsukuba. The cineradiographic system of Tsukuba University Hospital obstructs to film the volunteer's total motion. Observation of volunteers' cervical vertebra movement and observation of volunteers' head and torso motion can't be performed simultaneously.

A more detailed configuration and method of these sled tests were referred in Ono and Kaneoka [9], [14].

Table 2.
Summary of Volunteer Sled Tests

Test No.	Volunteer	Head-restraint	X-ray
V01	a	Yes	No
V02	b	Yes	No
V03	a	Yes	Yes
V04	b	Yes	Yes

Table 3 shows physical data for the volunteers. Volunteers, whose physiques resembled AM50 and without history of cervical spine injury, participated. It was confirmed through X- rays that they had no degenerative cervical spine irregularities.

Table 3.
Physical Data of Volunteers

Volunteer	a	b
height (cm)	174	172
sitting height (cm)	94	90
weight (kg)	70	61
age (year)	22	22

Head and Torso Motion

Figure 8 shows one subject's sequential motion in V01, and shows the target points for the analyses of the subject's head and torso motion. Time- historical volunteer motion in V01 test are shown in Figure 9. Here the reference point of the x- displacement is on the sled, and all the numerical values are initially zero.

Figure 8. Volunteer sequential motion during impact (V01).

The rearward head rotation is almost the same as the dummy's head rotation (Figure 6C and Figure 9C). However the rearward torso rotation is larger than the dummy's torso rotation, resulting in cancellation of rearward head rotation and a reduction of $\Delta\theta$ max.

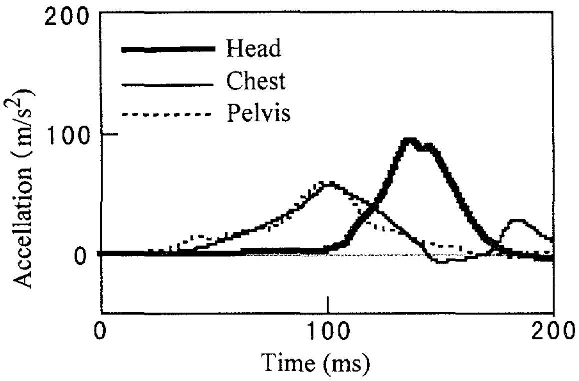

Figure 9A. Volunteer response (V01).

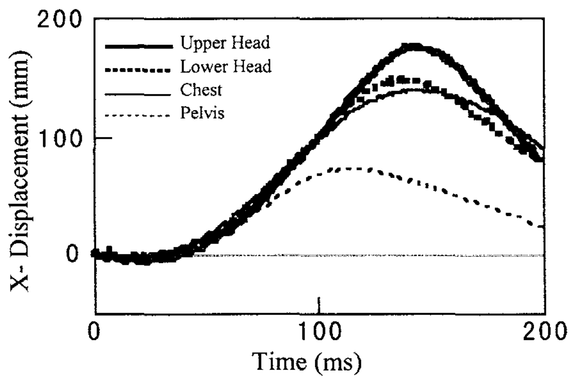

Figure 9B. Volunteer response (V01).

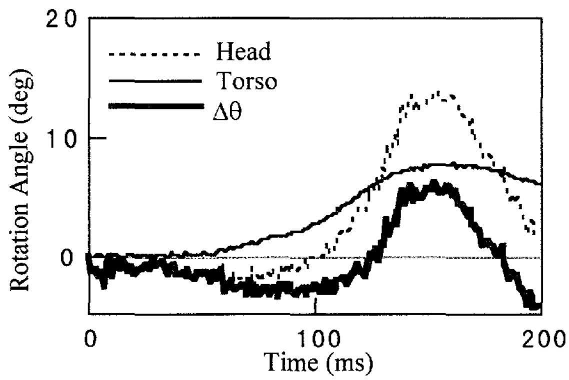

Figure 9C. Volunteer response (V01).

According to smoother spines curvature, more flexible shoulder joints and softer lumber spines of the human subjects, their upper torsos sink into the seat back and rebound much slower than pelvis, also resulting in cancellation of the rearward head rotation relative to the torso. Figure 10 shows time- historical electromyographic activities, arising approximately 60ms after impact, proves that the subject remained relaxed before impact.

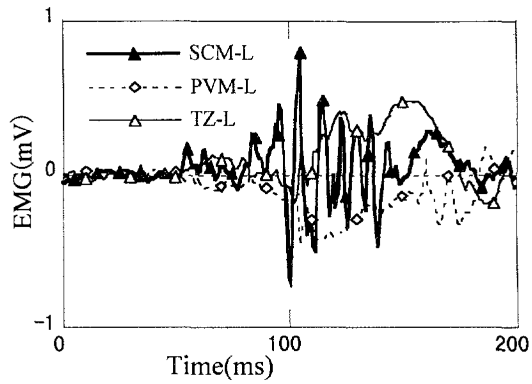

Figure 10. Electromyograph (V01).

On the other hand in V02 test (Figure 11) subject's head rotation and torso rotation showed all smaller values than in V01. Consequently $\Delta\theta$ max is identical to V01. The initial flexion mode of neck was clearly observed in V01, however only slightly observed in V02 as in the dummy sled tests. (Figure 6C, Figure 9C and Figure 11). In these tests even if only two cases, it is observed that each subject's head and torso motion was small.

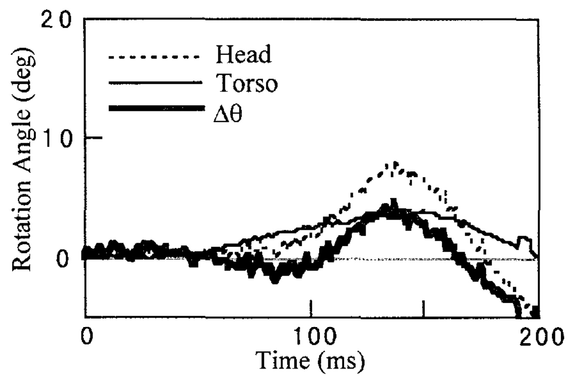

Figure 11. Volunteer response (V02).

In addition, each head and torso motion of the dummy is almost in the same range as the volunteers' motion. Considering the difference of initial gaps between head and head restraint, the dummy with the modified neck can be a surrogate in these low speed rear impact conditions except for the cervical vertebra.

Cervical Vertebra Movement

Figure 12 shows one subject's cervical vertebra sequential movement in V03, the same subject as in V01 test. In the case of V03 the maximum rearward rotation of the head is time- historically a little later than in V01. In the two tests the subject intend to sit identically, but might have had different seating positions, especially with regard to the initial gap.

Figure 13 shows time- historical cervical vertebra movement in test V03, and Figure 14 in test V04. The picture of cineradiography can't be obtained from the impact timing, because the field of cineradiographic vision is limited. So the initial picture is determined by the appearance of the subject's neck within the analyzable range.

Cervical vertebra response of the two subjects is in contrast with each other. In test V03, middle vertebra rotate rearward, followed by C6 and C2 vertebra. When the maximum rotation of C6 occurs cervical vertebra move in alignment, with C5- C2 in almost initial alignment. In test V04, lower vertebra rotate rearward, followed by upper vertebra. When the maximum rotation of C6 occurs the cervical vertebra move in alignment. In this case total neck motion shows extension however cervical vertebra movement shows flexion. This is because the torso moves rearward but the head moves forward supported by the head restraint.

In both tests cervical vertebra rotations between C6 and C2 are small, approximately only 10 degrees. Moreover it is observed that the human cervical vertebra behaved diversely. One is extension and the other is flexion.

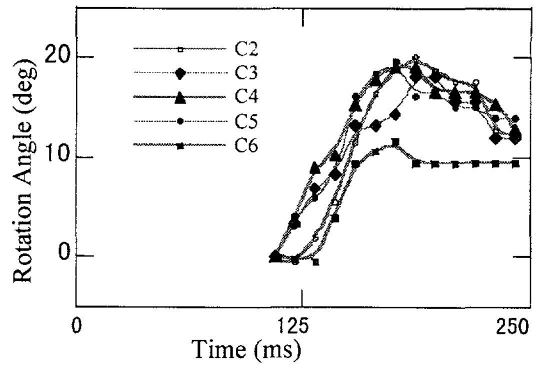

Figure 13. Cervical vertebra response (V03).

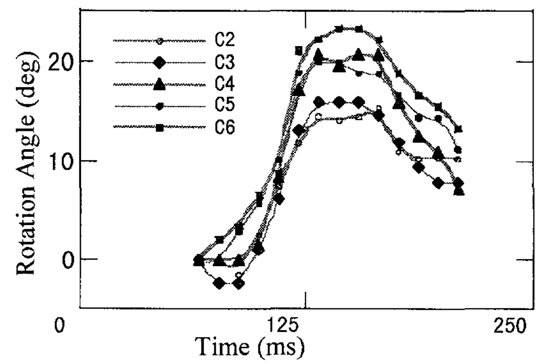

Figure 14. Cervical vertebra response (V04).

Maximum rotation angles of these two subjects' cervical vertebra are compared with the average maximum extension angle of human cervical vertebra in ordinary neck extension motion [15]. Each cervical vertebra in these two tests is within the normal range of movement, see Figure 15. Of course test V04 shows flexion motion as described.

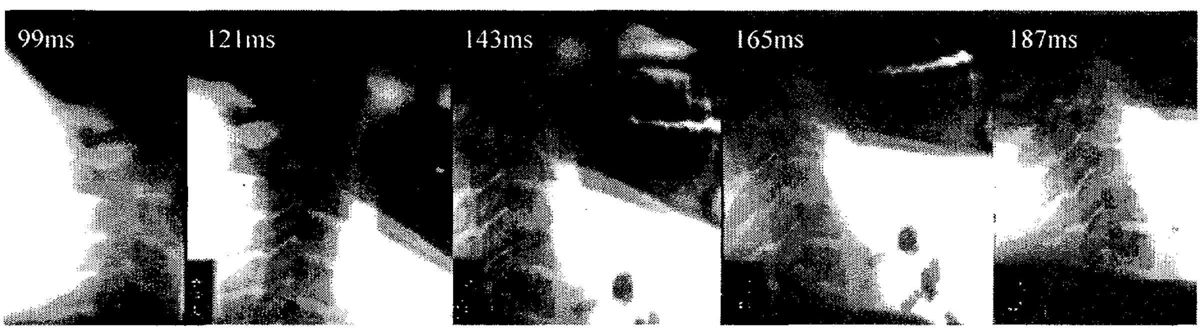

Figure 12. Volunteer cervical vertebra sequential movement during impact (V03).

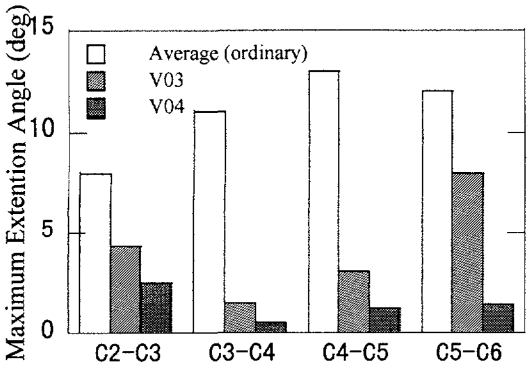

Figure 15. Maximum cervical vertebra rotation of these tests compared with ordinary neck extension.

Finally it must be mentioned that two volunteers suffered no injury to their necks in these tests.

CONCLUSIONS

The seat, which has new design concept for reduction in whiplash injuries, allows less motion between head and torso in the modified dummy sled tests, and also allows less motion in volunteer sled tests. Moreover there is less movement between each cervical vertebra.

Further research is required whether any other mechanism of whiplash injuries exists.

With head restraints, human motion between head and torso is similar to the modified dummy. Consequently a evaluation of head and torso motion is possible using a modified dummy, if limited to low-speeds. However, real human's neck motion, especially cervical vertebra movement, is too complicated and diverse to simulate by current dummies.

A more sophisticated rear impact dummy with higher bio-fidelity is needed for more accurate evaluation. Smoother spines curvature, softer lumber spines, more flexible shoulder joints are needed.

It. is important to remind occupants to adjust their head restraints properly according to manufacturers' recommendations so as to take advantage of the protection offered by the available head restraint.

<u>**Prius**</u>- Toyotas' brand new car. Its seats have the design concept as described in this paper.

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