FEMALE VOLUNTEER MOTION IN REAR IMPACT SLED TESTS IN COMPARISON TO RESULTS FROM EARLIER MALE VOLUNTEER TESTS

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ABSTRACT

Vehicle related crashes causing neck injuries (whiplash) are costly and common, and injury statistic data shows a larger risk of neck injuries for females than for males. This study aims at investigating differences between female and male dynamic response in rear impacts. Rear impact sled tests with female volunteers were carried out and the results were compared with previously performed tests with males in matching test conditions. The volunteer tests were performed at a change of velocity of 7 km/h. The comparison of the average response of the males and the females and their response corridors showed several differences. The horizontal head acceleration peak value was on average 40% higher and occurred on average 18% earlier for the female volunteers compared to the male volunteers. The NIC value was 45% lower and 30% earlier for the females, probably due to a 27% smaller initial head-to-head restraint distance and thereby a 24% earlier head restraint contact. The results provide characteristic differences between dynamic responses of females and males in low speed rear impacts. These results contribute to the understanding of human dynamic response in rear impacts. In addition, they can be used in the process of future development if numerical and/or mechanical human models for crash testing.

Keywords: WHIPLASH, VOLUNTEERS, KINEMATICS, REAR IMPACTS, SLED TESTS

IN THE EUROPEAN UNION it is estimated that more than 300 000 citizens suffer Whiplash Associated Disorders (WAD) from vehicle collisions every year. The associated socio-economic impact of these injuries is in the order of 4 billion Euros per year (Whiplashkommisionen, 2005). The injuries are found in all impact directions with rear impacts being the most common in terms of cause of injury in accident statistics. Since the end of the 1960's, epidemiological data has shown that females have 40-100% larger risk of sustaining WAD than males (among others Krafft *et al*., 1997 and Jakobsson *et al*., 2004). However, little is known about the differences between females and males in terms of dynamic response. Such response data is primarily established by performing volunteer tests. These test results are a necessary input for the development of improved occupant models (crash dummies and computational models).

METHODS AND MATERIALS

Volunteer rear impact sled tests were performed at the change of velocity of 7 km/h. The volunteers were fitted with accelerometers and film markers and placed in a laboratory seat. The laboratory seat was designed to resemble a car seat of the late 1990s and consisted of panels which enable the motion of the different parts of the seat back to be monitored during the impact. The film marker and accelerometer positions, sled system and seat were the same as those used in Davidsson et al. (1999).

Eight female volunteers with an average weight of 60 kg, height of 1.66 m, seating height of 0.88 m, neck circumference of 0.33 m, and an average age of 24 years were run on a sled that was rear impacted by a second, bullet-sled. The volunteers were healthy with no history of neck pain and were chosen to represent an average female. The test series were ethically approved by an ethical committee at LMU (Klinikum der Universität München, Ethikkommission), ref number 319-07, and before the tests the volunteers were examined by a medical doctor. The volunteers were instructed to sit in their own preferred position in the seat, look in the forward direction and relax prior to the test. Response corridors were generated as the average value ± one standard deviation (SD) for each time sample. These responses were compared to responses obtained from (Davidsson *et al.* 1999) which contains the average response of five males with an average weight of 77 kg, height of 1.82 m, seating height of 0.92 m, neck circumference of 0.37 m, and an average age of 30 years.

SLED - The sled used for the test series was a target-bullet sled in which the acceleration pulse (Fig. 1) was generated by a bending bar. The coordinate system was defined according to the SAE J211 standard.

INSTRUMENTATION - Tri-axial accelerometers were placed on the left side of the volunteers' head, approximately at the centre of gravity of the head. Two linear accelerometers, in x- and z-direction, were placed on a holder attached to the skin close to T1 (the upper thoracic vertebra). Linear accelerometers were placed on the bullet sled and on the target sled. A tape switch with a release force of 5N was attached to the steel bar on the target sled and the signal from this switch defined the start of the impact, T=0. The motion of the volunteers was monitored with high-speed video at 1000 frames per second.

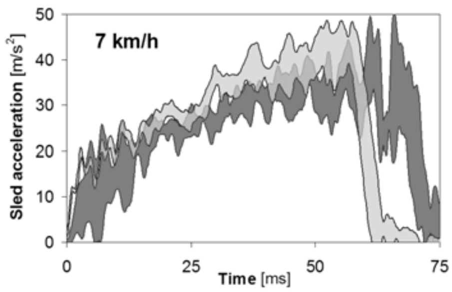

Fig. 1 *- The sled acceleration.*
The dark corridor represents tests with males and the light corridor represents tests with females.

The upper torso displacement angle was defined as the angle between the film mark placed at the T1 and the film mark placed at the clavicle. The horizontal displacement of the head and T1 were expressed relative to the sled coordinate system with the x-axis forward (in the sled travelling direction). The head-to-head restraint distance was measured before the test and the contact time was identified from film analysis. The Neck Injury Criterion (NIC) value was calculated according to Boström *et al.* (1996), and the accelerations for the NIC calculations were filtered in CFC60.

RESULTS

The comparison of the average response and the corresponding corridors of the males and the females showed several differences.

The horizontal head acceleration data (Fig. 2a) showed that the increase of the horizontal head acceleration started earlier for the females and that the peak acceleration for the females occurred earlier, and had a higher peak value, than the peak acceleration for the males. On average, the peak value for females was 72 m/s^2 at 119 ms compared to 51 m/s^2 at 145 ms for the males.

The increase of the horizontal T1 acceleration started earlier for the females compared to the males (Fig 2b). On average, it took 61 ms for the females and 74 ms for the males to reach the T1 acceleration 20 m/s^2. The peak values were of the same magnitude for the males and the females.

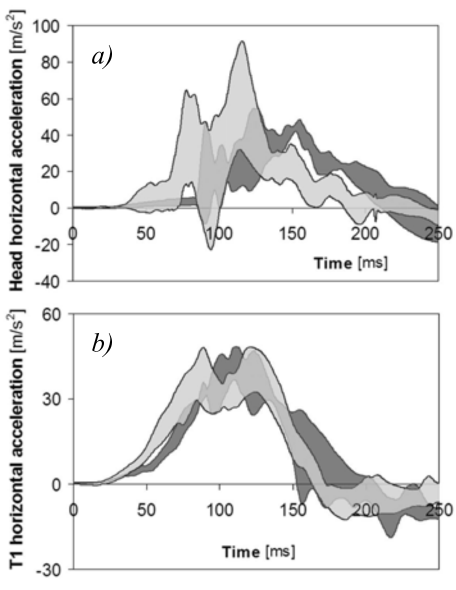

Fig. 2
a) The horizontal head acceleration.
b) The horizontal T1 acceleration.
The dark corridors represent tests with males and the light corridors represent tests with females.

The rearward horizontal displacement peaks of the head and T1 for the females were smaller and earlier than that of the males in the negative direction (Fig. 3a,b). The average value for the males was 149 mm at 144 ms and for the females it was 111 mm at 126 ms. The corresponding numbers for the horizontal T1 negative displacement were 100 mm at 122 ms for the males and 87 mm at 108 ms for the females.

The negative peak of the head relative T1 horizontal displacement (Fig. 3c) was smaller and earlier for the average female (40 mm at 163 ms) compared to the average male (79 mm at 186 ms).

The positive peak of the head angle (Fig. 3d) was larger for the males (24°) compared to the females (18°) while the positive peak of the upper torso angle (Fig. 3e) was larger for the females (19°) compared to the males (14°).

The first (negative) peak of the head relative upper torso angle (Fig. 3f) was smaller and earlier for the average male (6° at 100 ms) than the average female (9° at 117 ms). The second (positive) peak was larger and earlier for the males (12° at 180 ms) than the females (7° at 208 ms).

The average NIC value for the females was lower and earlier (3.4 m^2/s^2 at 62 ms) compared to the males (6.3 m^2/s^2 at 88 ms).

The initial head-to-head restraint distance was on average smaller for the females (62 mm) compared to the males (86 mm) and the head-to-head restraint contact occurred on average earlier for the females (71 ms) compared to the males (94 ms).

DISCUSSION

The horizontal head acceleration peak value was on average 40% higher and occurred on average 18% earlier for the female volunteers compared to the male volunteers. Similar results have been reported by Hell *et al.* (1999) and Carlsson *et al.* (2008). The earlier occurrence of the head acceleration peak for the female volunteers in the present study may be due to smaller initial head-to-head restrain distance for the females (62 mm) compared to the males (86 mm). Smaller head-to-head restraint distance for females has also been reported by Jonsson *et al.* (2007), for all seating positions in a Volvo V70.

The smaller initial head-to-head restraint distance for the females resulted in an earlier head-to-head restraint contact time, a smaller horizontal head displacement and head extension angle, and lower NIC values. Since the head-to-head restraint contact occurred earlier for the females, and the contact force between the upper torso and seat structure peaked after the head-to-head restraint contact, the relative acceleration between the head and T1 was smaller for the females, leading to a lower NIC value for females than for males. The NIC value was on average 45% lower and 30% earlier for the female volunteers compared to the male volunteers. Similar differences in the NIC value between

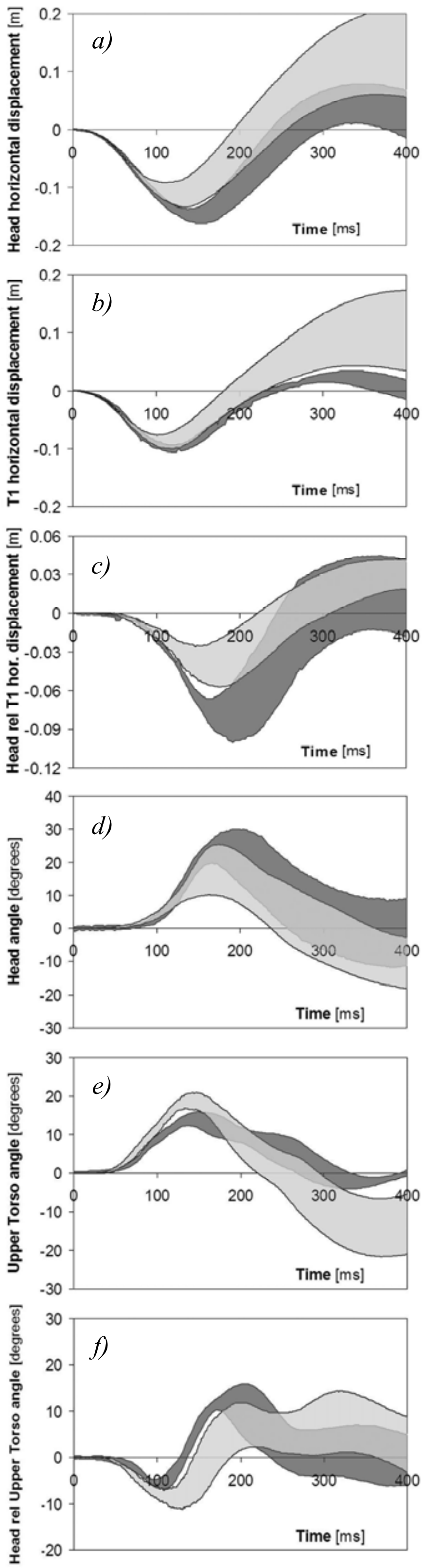

Fig. 3
a) The horizontal head displacement.
b) The horizontal T1 displacement.
c) The horizontal head rel. T1 displacement.
d) The head angular displacement.
e) The upper torso angular displacement.
f) The head rel. upper torso angular displacement.
The dark corridors represent tests with males and the light corridors represent tests with females.

female and male volunteers have been reported by Carlsson *et al.* (2008).

The increase of the T1 horizontal acceleration started earlier for the females compared to the males which is consistent with what has been reported by Hell *et al.* (1999) and Ono *et al.* (2006).

Further studies are needed of both male and female volunteers in car seats in order to establish their dynamic response in rear impacts. Such data is fundamental in order to develop mathematical and mechanical models of both males and females for rear impact tests. These models are essential in order to develop and evaluate the performance of new anti-whiplash systems for all adult occupants.

CONCLUSIONS

This paper quantifies the differences between female and male volunteer response in a rear impact. The data showed that the head x-acceleration peak value was 40% higher and 18% earlier for the females compared to the males. The NIC value was 45% lower and 30% earlier for the females, probably due to a 27% smaller initial head-to-head restraint distance and thereby a 24% earlier head restraint contact. These results contribute to the understanding of human dynamic response in rear impacts. In addition, they can be used in the process of future development of numerical and/or mechanical human models for crash testing.

ACKNOWLEDGEMENTS

This study was funded by the Swedish Governmental Agency for Innovation Systems (VINNOVA). Special thanks for valuable help with data collection and processing to Kristin Thorsteinsdottir at LMU and Carsten Reinkemeyer at Allianz.

REFERENCES

Boström, O., Krafft, M., Aldman B., Eichberger, A., Fredriksson, R., Håland Y., Lövsund P., Steffan, H., Svensson, M.Y., Tingvall, C. (1997): *Prediction of Neck Injury Based on Accident Data and Simulations.* Proc. IRCOBI conf., Hannover, Germany, pp. 251-283.

Carlsson, A., Linder, A., Svensson, M., Siegmund, G. (2008): *Dynamic Responses of Female and Male Volunteers in Rear Impacts*. World Congress on Neck Pain, Los Angeles, USA

Davidsson, J., Flogård, A., Lövsund, P., and Svensson, M.Y. (1999): *BioRID P3 - Design and performance compared to Hybrid III and volunteers in rear impacts at ΔV=7 km/h*. (99SC16). Proc. 43rd Stapp Car Crash Conference, pp. 253-265. Society of Automotive Engineers, Warrendale, PA.

Hell, W., Langwieder, K., Walz, F., Muser, M., Kramer, M., Hartwig, E. (1999): *Consequences for Seat Design due to Rear End Accident Analysis, Sled Tests and Possible Test Criteria for Reducing Cervical Spine Injuries after Rear-End Collision*. Proc. IRCOBI conf., Sitges, Spain, pp. 243- 259.

Jakobsson L. Norin, H., Svensson, M.Y. (2004): *Parameters Influencing AIS 1 Neck Injury Outcome in Frontal Impacts*. Traffic Inj. Prev., Vol. 5, No 2, pp. 156–163.

Jonsson B., Stenlund H., Svensson M.Y. and Björnstig U. (2007): *Backset and Cervical Retraction Capacity among Occupants in a Modern Car*. Traffic Inj. Prev., Vol. 8, No 1, pp. 87–93.

Krafft M, Kullgren A, Lie A, Nygren Å, Tingvall C. (1997): *Soft Tissue Injury of the Cervical Spine in Rear-end End Car Collisions*. Traffic Medicine, 25(3-4).

Ono K, Ejima S, Suzuki Y, Kaneoka K, Fukushima M, Ujihashi S (2006): *Prediction of neck injury risk based on the analysis of localized cervical vertebral motion of human volunteers during low-speed rear impacts.* Proc. IRCOBI conf., Madrid, Spain, pp. 103-113.

Whiplashkommissionen (2005): http://www.whiplashkommissionen.se/pdf/WK_finalreport.pdf