Motion of the Head and Neck of Female and Male Volunteers in Rear Impact Car-to-Car Tests at 4 and 8 km/h

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ABSTRACT

In this study indications of differences in motion pattern of females and males have been found. The objective was to quantify dynamic motion responses of female and male volunteers in rear impact tests. Such data can be used as an input in the development process of improved occupant models such as computational models and crash test dummies.

High-speed video data from rear impact tests at 4 km/h and 8 km/h with 12 female and 11 male volunteers was analysed. The females in this study had smaller rearward horizontal and angular motions of the head and T1 compared to the males. Furthermore, the females had more pronounced rebound motion.

Key Words: Whiplash, Volunteers, Kinematics, Rear Impacts

WHIPLASH ASSOCIATED DISORDER (WAD), commonly denoted whiplash injury, is a worldwide problem. These injuries are costly since they are frequent and can lead to long lasting pain and disability. In Europe, the yearly cost for whiplash injuries has been estimated to be 10 billion Euros (Richter et al. 2000). In USA, the annual number of whiplash injuries has been estimated to 800,000. Of these whiplash injuries, 270,000 resulted from rear impacts with an annual cost of $2.7 billion (NHTSA 2004). In Japan, 547,654 traffic related injuries were registered during 1996 and 44% suffered from neck injury (Watanabe et al. 2000). Whiplash injuries account for ~70% of all injuries leading to disability, induced by modern vehicle crashes (Kullgren et al. 2007). The majority of those who experience initial neck symptoms after the car crash recover, most within a week of the crash. However, 5-10% of individuals will experience permanent disabilities of varying degrees (Nygren et al. 1985; Krafft 1998; the Whiplash Commission 2005). These injuries occur at relatively low changes of velocities (typically <25 km/h) (Eichberger et al. 1996; Kullgren et al. 2003), and in impacts from all directions. Rear impacts, however, are most common in the accident statistics (Watanabe et al. 2000).

Females have a higher risk of sustaining whiplash injuries than males, even under similar crash conditions (Narragon 1965; Kihlberg 1969; O'Neill et al. 1972; Thomas et al. 1982; Otremski et al. 1989; Maag et al. 1990; Morris & Thomas 1996; Dolinis 1997; Temming & Zobel 1998; Richter et al. 2000; Chapline et al. 2000; Krafft et al. 2003; Jakobsson et al. 2004; Storvik et al. 2009). According to these studies the whiplash injury risk is between 1.5–3 times higher for females compared to males.

Differences in the physiology of the head/neck for males and females may contribute to the increased whiplash injury risk for females. It has been reported that females have lower strength in their neck muscles (Foust et al. 1973; Vasavada et al. 2001; Vasavada et al. 2008), and faster neck muscle reflexes (Foust et al. 1973; Siegmund et al. 2003). Females have smaller necks relative to their head size compared to males (States et al. 1972). Males have larger vertebral dimensions than females (DeSantis Klinich et al. 2004; Stemper et al. 2008; Vasavada et al. 2008), and larger segmental support area indicating a more stable intervertebral coupling (Stemper et al. 2008). Differences in ligament structural components may lead to decreased stiffness in female spines (Stemper et al. 2008). The total range of extension–flexion motion is larger for females compared to males (Buck et al. 1959; Foust et al. 1973), while the total range of retraction–protraction motion is smaller (in seated posture) (Hanten et al. 1991; Hanten et al. 2000). In dynamic tests, a more pronounced S-curved shape of the neck has been reported for females compared to males (Stemper et al. 2003, Ono et al. 2006).

Differences in anthropometry and mass distribution of males and females may affect the interaction between the upper body and the seatback/head restraint, and may contribute to the increased whiplash injury risk for females. The shorter stature of females affects the geometry and the motion of the head relative to the head restraint. A lower mass and/or a lower centre of mass not only decreases the deflection of the seatback padding and springs, but also decreases the deflection of the seat frame due to a smaller lever about the seatback hinge. Smaller seatback deflection affects the plastic deformation and energy absorption as well as the dynamic head-to-head restraint distance and the rebound of the torso (Svensson et al. 1993; Croft 2002; Viano 2003). Females have in comparison to males higher head x-acceleration, higher (or similar) T1 x-acceleration, lower (or similar) Neck Injury Criterion (NIC) value, and more pronounced rebound (Szabo et al. 1994; Siegmund et al. 1997; Hell et al. 1999; Welcher & Szabo 2001; Croft et al. 2002; Mordaka & Gentle 2003; Viano 2003; Ono et al. 2006; Carlsson et al. 2008; Linder et al. 2008; Schick et al. 2008).

Differences in seat geometry for females and males may have an influence on the dynamic response during the collision. It has been reported that females tend to sit in a more upright position, with a 3° smaller seatback angle, than males (Jonsson et al. 2008). Several studies have reported a shorter head-to-head restraint distance for females compared to males (Szabo et al. 1994 (estimation from graph); Minton et al. 1997; Jonsson et al. 2007; Linder et al. 2008; Schick et al. 2008; Carlsson 2008).

The 50th percentile male crash test dummy roughly corresponds to a 90th-95th percentile female in terms of stature and mass (Welsh & Lenard 2001), but does not correlate in terms of mass distribution and dynamic response. Hence, females are not well represented by the existing rear impact 50th percentile male dummies: the BioRID and the RID3D. Consequently, the current seats are optimized to the 50th percentile male with no consideration of female properties, in spite of the higher whiplash injury risk for females.

Dynamic response of both females and males needs to be established in order to understand the biomechanics that form the basis for whiplash injury. The primary source of such dynamic response data is from comparable volunteer tests with males and females. This data can be used as an input in the development process of improved occupant models such as computational models and crash test dummies.

The objective of this study was to quantify dynamic motion responses of female and male volunteers in rear impact tests. Such data is fundamental in order to develop mathematical and mechanical models of both males and females for rear impact tests. These models can be used, not only as a tool in the design of protective systems, but also in the process of further evaluation and development of injury criteria.

METHODS

Data from a rear impact test series with 21 male and 21 female volunteers at 4 km/h and 8 km/h, originally presented in Siegmund et al*.* (1997), were used for further analysis. A subset representing the 50th percentile female was extracted in a similar way as the subset representing the 50th percentile male in Siegmund et al. (2001). Initial results from the present study regarding head-to-head restraint distance, head-to-head restraint contact, and head/T1 accelerations were published in Linder et al. (2008). Further analysis of the high-speed video data was the focus of this publication. In this study an extension of the dataset (from ~280 ms to ~350 ms) for the female volunteers at 8 km/h was generated by additional analysis of the film data. Peak values and their timing were derived from the data and response corridors were generated for the females and the males.

TEST PROCEDURES: The following description of the test procedure and data reduction is a summary of the description found in Siegmund et al*.* (1997). The volunteers were seated in the front passenger seat of a 1990 Honda Accord LX 4-door sedan. The rear of the Honda was struck by the front of a 1981 Volvo 240DL station wagon for the volunteer tests. The Volvo's impact speeds were selected to produce speed changes of about 4 km/h and 8 km/h on the Honda. The Honda's passenger seat was locked in the full rear position and the initial seat back angle was set to about 27 degrees from vertical for all tests. The head restraint was locked in the full-up position. The volunteers were restrained by a lap and shoulder seat belt. The volunteers were instructed to sit normally in the seat, face forward with their head level, place their hands on their lap, and relax prior to impact. The volunteers knew an impact was imminent, but could not predict its exact timing.

Each volunteer underwent two tests: one each at a change of velocity of 4 km/h and 8 km/h. No demonstration trials or practice were given and the two tests were separated by at least one week in order to minimize the effect of habituation. The volunteers were instrumented with accelerometers and video markers as described in detail in Siegmund et al*.* (1997).

Kinematic data and head restraint load data were resolved into a global reference frame with the x-axis horizontal and positive forward, the y-axis horizontal and positive to the right, and the z-axis vertical and positive downward. In this reference frame, extension motions were positive and flexion motions were negative. Kinetic data at the atlanto-occipital (AO) joint were resolved to the head reference frame, in which the z-axis was positive in the inferior direction. The instantaneous orientation of the head reference frame relative to the global reference frame was determined from the high-speed video.

HUMAN SUBJECTS: The male corridors presented in Siegmund et al*.* (2001) were derived using data from 11 of the original 21 male subjects from Siegmund et al*.* (1997) (shaded in **Table 1**). These subjects were selected based on a stature range (173–178 cm) that was within ±3 cm of a 50th percentile male (174.7 cm; Diffrient et al. 1974). Their weight range (63–87 kg) varied between the 10th and 75th percentile mass for males of the 50th percentile stature (Najjar & Rowland 1987). The females were selected in a similar way. Of the original 21 female subjects 9 volunteers (at 8 km/h) and 12 (at 4 km/h) were selected (shaded in **Table 1**). These subjects were selected based on a stature range (156–167 cm) within ±5.5 cm of a 50th percentile female (161.5 cm; Diffrient et al. 1974). Their weight range (45.8–83.4 kg) varied between the 5th and 90th percentile mass for females of the 50th percentile stature (Najjar & Rowland 1987).

The stature and weights for all volunteers are shown in **Fig. 1**. In addition, the figure also contains data of the average female and male as defined by Diffrient et al. (1974) and Najjar and Rowland (1987). The selection of the female volunteers resulted in a wider stature interval (±5.5 cm) compared to the males (±3 cm). This was done in order to get a comparable number of female and male volunteers (12 females at 4 km/h, 9 females at 8 km/h, and 11 males at both velocities).

The average age of the volunteers was 26 years for the males and 27 years for the females.

Table 1. Age, stature, and weight of the volunteers (Siegmund et al. 1997). The subset of volunteers representing the 50th percentile male (Siegmund et al. 2001) and the 50th percentile female, are shaded.

MALE				FEMALE			
No.	Age [years]	Stature [cm]	Weight [kg]	No.	Age [years]	Stature [cm]	Weight [kg]
20	25	164.5	81.5	54	22	153.5	54.5
16	37	168.0	69.0	52	21	155.0	57.0
43	21	168.5	50.9	**19**	**25**	**156.0**	**60.0**
05	30	171.0	92.0	**62**	**28**	**159.0**	**62.5**
25	**25**	**173.0**	**69.1**	**61**	**27**	**161.5**	**62.0**
27	**22**	**173.0**	**70.7**	**63**[2)]	**20**	**162.0**	**45.8**
17	**27**	**173.0**	**83.5**	**44**	**33**	**162.0**	**65.1**
04	**33**	**174.0**	**66.1**	**23**	**31**	**163.0**	**58.7**
22[1)]	21	174.0	72.0	**33**	**33**	**163.0**	**63.7**
46	**22**	**174.0**	**86.5**	**32**[2)]	**30**	**164.0**	**65.7**
15	**27**	**175.0**	**85.5**	**11**	**25**	**165.0**	**83.4**
18	**27**	**175.5**	**64.0**	**49**	**28**	**167.0**	**52.5**
50	**22**	**175.5**	**69.0**	**42**	**21**	**167.0**	**53.6**
35	**30**	**176.0**	**76.8**	**26**[2)]	**27**	**167.0**	**62.5**
03	**25**	**177.0**	**74.4**	57	41	168.0	62.0
28	**22**	**178.0**	**62.8**	53	25	168.0	63.0
09	32	178.5	82.9	13[1)]	25	168.0	70.0
14	21	182.5	79.0	56	24	168.0	72.0
34	28	183.0	73.4	58	27	168.5	57.0
01	26	183.5	79.9	48	30	170.5	58.0
47	30	185.0	84.0	12	27	173.5	80.0

1) The data set is not complete, the subject is excluded.
2) These three subjects chose not to participate in the 8 km/h test.

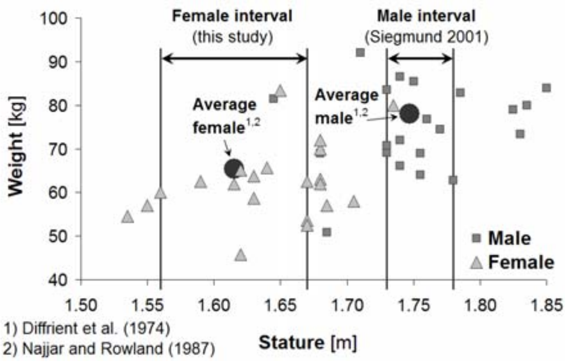

Fig. 1 - The stature and weight for all volunteers (Siegmund et al. 1997). The range of statures of the chosen subset of females for this study, and the subset of males from Siegmund et al. (2001) are illustrated with vertical lines. From the literature, the average male and female, as defined by Diffrient et al. (1974) and Najjar & Rowland (1987), are represented by filled circles.

RESULTS

Response corridors were generated for the x- and angular displacements of the head, T1, and head relative to T1 for the male and female volunteers. The corridors were defined as the average ± one standard deviation (SD) from the average response.

X-DISPLACEMENTS: The females had, in comparison to the males, a lower and earlier peak rearward displacement of the head, T1, and head relative to T1 (negative values in **Fig. 2a-f, Table 2**). For example, at 8 km/h the peak rearward x-displacement of the head was 12% lower and occurred 6% earlier for the females compared to the males. Similarly, for T1 the peak rearward displacement was 8% lower and occurred 5% earlier, and for the head relative to T1 it was 22% lower and occurred 9% earlier for the females compared to the males.

The rebound motion was more pronounced for the females compared to the males, with an earlier return to the initial position of the head and T1 (=0 cm) and a larger forward displacement at the end of the data set (positive values in **Fig. 2a-f**). At 8 km/h, the heads of the females returned to their initial positions 10% earlier than the heads of the males; a similar trend was recorded for the T1 (11% earlier), and for the head relative to T1 (8% earlier). The forward displacement of the head at the end of the data set was 77% larger for the females at 8 km/h than the males. For the T1, and the head relative to T1, the forward displacement at the end of the data set was 68% and 179% larger, respectively, for females than males.

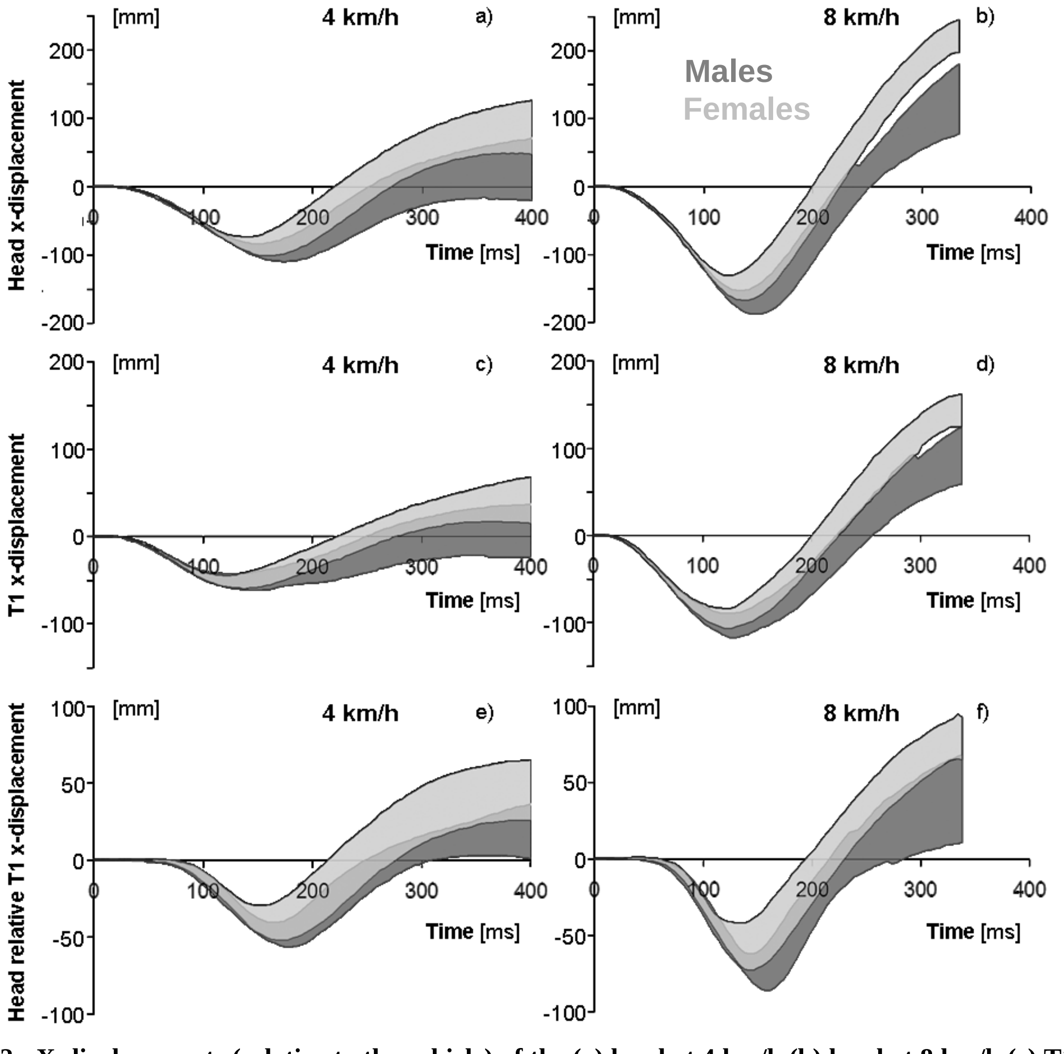

Fig. 2 - X-displacements (relative to the vehicle) of the (a) head at 4 km/h (b) head at 8 km/h (c) T1 at 4 km/h (d) T1 at 8 km/h (e) head relative to T1 at 4 km/h (f) head relative to T1 at 8 km/h. The response corridors are calculated from the average ±1SD from the average response. Dark grey corridors represent males and light grey corridors females.

ANGULAR DISPLACEMENTS: The peak rearward angular displacements of the head and T1 (positive angles in **Fig. 3a-d, Table 2**) were lower and occurred earlier for the females compared to the males at both 4 km/h and 8 km/h. On average, the peak rearward angular displacement of the head was 30% lower and occurred 7% earlier for the females at 8 km/h. Likewise, T1 was 9% lower and occurred 9% earlier for the females at 8 km/h. Since the rearward angular displacement of T1 started earlier in comparison to the head, the volunteers exhibited a small flexion of the head relative to T1 during the first ~100 ms (negative angles in **Fig. 3e-f**). This flexion was, for the females in comparison to the males, 17% higher at 4 km/h, while at 8 km/h it was 6% lower. As the head started to rotate rearward, the flexion of the head relative to T1 changed into an extension (positive angles in **Fig. 3e-f**), except for the females at 8 km/h with an average maximum of 0°, i.e. they did not enter into extension.

During the rebound phase, the head and T1 angles of the females returned to their initial positions (=0°) earlier compared to the males, and they had larger forward flexion at the end of the data set (negative angles in **Fig. 3a-d**). At 8 km/h, the heads of the females returned to their initial positions 7% earlier than did the males, and they had 123% larger forward flexion at the end of the data set. The corresponding results for T1 were a 23% earlier return to their initial position, and 700% larger forward flexion at the end of the data set.

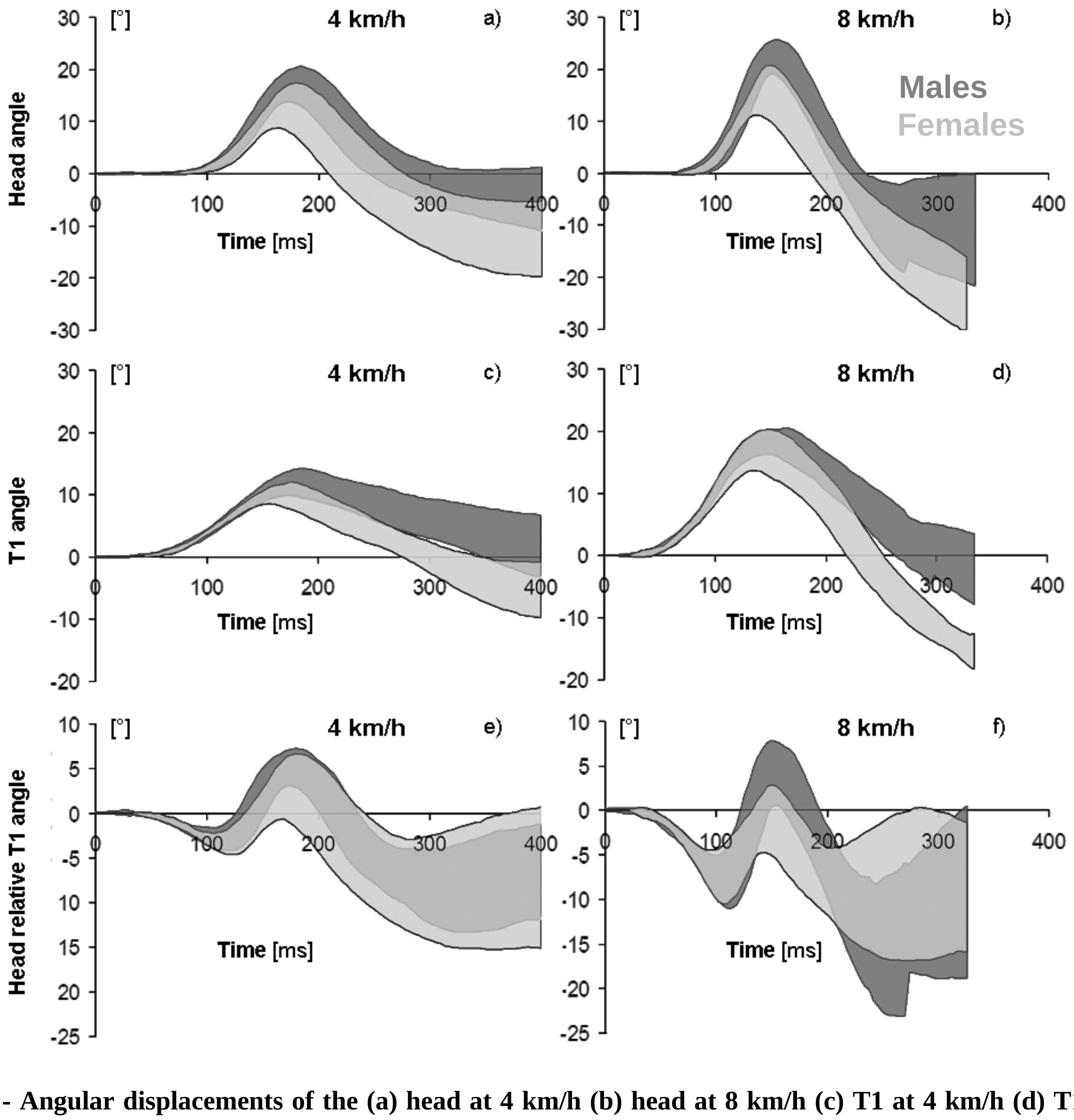

Fig. 3 - Angular displacements of the (a) head at 4 km/h (b) head at 8 km/h (c) T1 at 4 km/h (d) T1 at 8 km/h (e) head relative to T1 at 4 km/h (f) head relative to T1 at 8 km/h. Dark grey corridors represent males and light grey corridors females. Positive angles correspond to rearward bending. The discontinuity in Fig. 3b and f is due to variations in the length of data sampling time between different test subjects.

Table 2. The average x- and angular displacement peaks and their timing for the head, T1, and head relative to T1 for the male and female volunteers at 4 km/h and 8 km/h. Standard deviations in parenthesis and p-values from t-tests.

		X-displacement						Angular displacement							
		Head		T1		Head rel T1		Head		T1		Head rel. T1 Peak 1		Head rel. T1 Peak 2	
		[mm]	[ms]	[mm]	[ms]	[ms]	[ms]	[°]	[ms]	[°]	[ms]	[°]	[ms]	[°]	[ms]
4 km/h	Male	-97	161*	-53	137	-49	172	17.7*	177	12.2*	186*	-3.1	109	5.8	177
		(12)	(12)	(9)	(12)	(7)	(12)	(2.7)	(12)	(2.0)	(19)	(1.2)	(13)	(1.7)	(15)
		p=0.122	p=0.048	p=0.877	p=0.157	p=0.076	p=0.139	p=0.009	p=0.242	p=0.023	p=0.005	p=0.332	p=0.507	p=0.107	p=0.442
	Female	-89	150*	-52	130	-43	162	13.7*	170	10.3*	166*	-3.6	113	3.9	171
		(13)	(14)	(8)	(9)	(10)	(18)	(3.8)	(15)	(1.7)	(12)	(1.3)	(11)	(3.3)	(21)
8 km/h	Male	-170*	141*	-104	127*	-75*	149*	23.1*	152*	18.9	154*	-8.1	106	4.8*	154*
		(18)	(8)	(13)	(6)	(13)	(10)	(3.5)	(8)	(2.0)	(17)	(3.0)	(6)	(3.9)	(10)
		p=0.018	p=0.028	p=0.138	p=0.013	p=0.018	p=0.014	p=0.001	p=0.010	p=0.184	p=0.048	p=0.728	p=0.089	p=0.005	p=0.021
	Female	-149*	132*	-95	121*	-58*	136*	16.2*	142*	17.2	141*	-7.6	100	0*	142*
		(19)	(8)	(11)	(4)	(15)	(11)	(4.5)	(8)	(3.4)	(10)	(3.1)	(9)	(3.4)	(12)

* Statistical significant (p<0.05) difference between female and male average parameter values according to t-test. The calculations were based on the assumption that the data was normally distributed.

DISCUSSION

A further analysis of high-speed video data from a series of rear impact sled tests at 4 km/h and 8 km/h with female and male volunteers was performed. The volunteers were representative of the 50th percentile male and female in terms of stature, but less so in terms of weight. In an initial analysis based on the same data set (Linder et al. 2008), it was found that the females in comparison to the males had:

- higher and earlier peak x-acceleration of the head (32% higher and 7% earlier at 4 km/h, 10% higher and 9% earlier at 8 km/h).
- higher peak x-acceleration of the T1 (17% higher and 6% earlier at 4 km/h, and 16% higher at 8 km/h).
- shorter head-to-head restraint distance (8% at 4 km/h and 9% at 8 km/h).
- earlier head-to-head restraint contact (11% at 4 km/h and 9% at 8 km/h). For the same initial head-to-head-restraint distance, head restraint contact was ~11 ms and ~7 ms earlier for the females than the males at 4 km/h and 8 km/h respectively.
- similar Neck Injury Criteria (NIC) value as the males at 4 km/h, and 20% lower and 5% earlier NIC value at 8 km/h.

These results are summarized in **Table 3**.

Table 3. The average x-acceleration peaks and their timing for the head and T1, the head-to-head restraint distance and contact time, and the Neck Injury Criterion (NIC) for the male and female volunteers at 4 km/h and 8 km/h. Standard deviations in parenthesis and p-values from t-tests. Data from the study by Linder et al. (2008).

		X-acceleration				Head-to-head restraint		Neck Injury Criterion	
		Head		T1		Distance	Contact	NIC	
		[m/s^2]	[ms]	[m/s^2]	[ms]	[mm]	[ms]	[m^2/s^2]	[ms]
4 km/h	Male	30.0* (4.2)	159* (12)	18.3* (2.7)	122 (25)	45 (15)	128 (14)	1.91 (0.35)	105 (13)
		p=0.001	p=0.053	p=0.022	p=0.413	p=0.639	p=0.058	p=0.760	p=0.610
	Female	39.5* (5.5)	149* (12)	21.5* (3.4)	115 (14)	41 (18)	114 (19)	1.96 (0.44)	107 (9)
8 km/h	Male	83.7 (12.6)	140* (6)	38.6 (6.8)	124 (23)	43 (17)	100 (10)	4.04* (0.77)	97 (10)
		p=0.128	p=0.001	p=0.073	p=0.893	p=0.588	p=0.066	p=0.045	p=0.378
	Female	92.4 (11.3)	128* (7)	44.7 (7.2)	123 (15)	39 (17)	91 (10)	3.22* (0.93)	92 (11)

* Statistical significant ($p<0.05$) difference between female and male average parameter values according to t-test. The calculations were based on the assumption that the data was normally distributed.

The rearward peak x-displacements of the head, T1, and head relative to T1 were lower and occurred earlier for the females compared to the males at both 4 km/h and 8 km/h. Similar results have been reported in other rear impact studies (Szabo et al. 1994; Welcher & Szabo 2001; Carlsson et al. 2008). Szabo et al. (1994) reported that the female volunteers on average had a 24% lower peak rearward head x-displacement, and a 26% lower peak rearward shoulder x-displacement. Welcher & Szabo (2001) found the head relative to T1 rearward x-displacement was 10% lower (at 4 km/h) and 23% lower (at 8 km/h) for the 50th percentile female volunteer in comparison to the 50th percentile male volunteer. Carlsson et al. (2008) found that the peak rearward head, T1, and head relative to T1 x-displacements were lower and earlier for 50th percentile female volunteers compared to 50th percentile male volunteers. Thus, the results found in the present study correspond to previous findings, with lower and earlier peak head and T1 x-displacements for females compared to males.

The peak rearward angular displacements of the head and T1 in the present study were lower and had an earlier timing for the females compared to the males at both 4 km/h and 8 km/h. Similar results were found in Carlsson et al. (2008) for the head (29% lower at 7 km/), while for T1 the peaks were higher (33% higher at 7 km/) for the females compared to the males. The different results for the rearward angular displacement of the T1 for males and females found in the present study and in Carlsson et al. (2008) may be due to different interaction between the upper torso and the seatback.

Shorter head-to-head restraint distances for females before the impact (Szabo et al. 1994; Minton et al. 1997; Jonsson et al. 2007; Linder et al. 2008; Schick et al. 2008; Carlsson et al. 2008) may contribute to lower peak x-displacements of the head for the females compared to the males. During the impact, lower peak x-displacements of the T1 may be due to the smaller mass of the females compared to the males, i.e. heavier males may sink into and/or deflect the seatback to a greater extent. Smaller seatback deflection affects the plastic deformation and energy absorption as well as the dynamic head-to-head restraint distance and the rebound of the torso (Svensson et al. 1993; Croft 2002; Viano 2003).

Females had a more pronounced rebound than males in the present study. They had an earlier return to their initial position and a larger forward x-displacement/flexion at the end of the data set, for both the head and T1. Similar results have been reported in previous studies (Hell et al. 1999; Croft et al. 2002). Hell et al. (1999) reported that "most male volunteers showed a different head flexion behaviour (rebound, minor forward flexion) compared to female volunteers (clear forward flexion)". Croft et al. (2002) wrote about females that "due to her lesser body mass, she interacted faster with the seat back and head restraint and offered less resistance to their forward motion. This quicker interaction resulted in her earlier and higher amplitude acceleration." About males they wrote that males “offered greater resistance to the forward moving seat, effectively delaying their forward acceleration.” The findings reported in Hell et al. (1999) and Croft et al. (2002) are thus supported by the results in the present study. There are also other studies reporting higher and earlier peak head and/or T1 accelerations for females (Szabo et al. 1994; Mordaka & Gentle 2003; Viano 2003; Schick et al. 2008; Carlsson et al. 2008; Ono et al. 2006). If whiplash injuries occur during the rebound phase of a rear impact (von Koch et al. 1995; Muser et al. 2000), then the gender differences we observed in rebound behaviour may help explain why females experience more injuries than males.

Lower (or similar) NIC values have been reported for females compared to males (Welcher & Szabo 2001; Linder et al. 2008; Carlsson et al. 2008). This may be due to the shorter initial head-to-head restraint distance and earlier head-to-head-restraint contact for females. The results of this study may appear contradictory to the fact that the risk of whiplash injury is higher for females compared to males. Given the higher whiplash injury risk for females, one might ask whether the NIC threshold is different for females and males. Further research is needed in order to address this question.

Studies have shown that the BioRID 50th percentile male dummy is more biofidelic in low speed rear impact testing than the Hybrid III dummy (Davidsson et al. 1999; Philippens et al. 2002). The dynamic response of the BioRID 50th percentile male dummy has been evaluated with regards to low-speed rear impact tests with male volunteers (Davidsson et al. 1999). The results from the present study together with results from the previous study (Linder et al. 2008) show that the female volunteers had a different dynamic response than the male volunteers. It is therefore worrying that new whiplash protection systems are being developed and evaluated without considering the gender differences in dynamic responses and injury potential. Mordaka & Gentle (2003) concluded, based on mathematical simulations, that a “scaled down male model is not adequate to simulate female responses even though the scaling constitutes a good height and mass match”. Additionally, Vasavada et al. (2008) found that “male and female necks are not geometrically similar and indicate that a female-specific model will be necessary to study gender differences in neck-related disorders”. That is, a female model needs to be based on data from tests with females. The results from this study can become a valuable input to the development and validation process of such a model.

LIMITATIONS IN THIS STUDY: In this study one particular vehicle model was used as target and bullet vehicle, respectively. Another crash configuration may have resulted in other volunteer dynamic responses. For example, the head restraint was locked in the full-up position in all tests. According to Viano and Gargan (1996), 75.6% of adjustable headrests were in the lowest possible configuration; and of these, 90.6% could have been adjusted to a higher position relative to the head of the driver. Thus the subjects here had better head restraint protection than many real-world exposures. In addition, a larger number of volunteers would be needed in order to create robust confidence interval.

RECOMMENDATIONS:

In the future, this study could be used to develop and validate a mechanical and/or mathematical 50th percentile female dummy model for rear impact safety assessment. Such a model could be of use, not only to design and develop protective systems, but to further evaluate and develop injury criteria. A model of an average female could, together with the existing 50th percentile male model, complement the studies of Kullgren et al. (2003) and Linder et al. (2004), and be used to define gender-specific neck injury threshold values.

CONCLUSIONS

This paper quantifies the dynamic motion response of the head and T1 (first thoracic vertebrae) of 12 female and 11 male volunteers exposed to rear impact car-to-car tests at 4 km/h and 8 km/h. The overall result showed differences in the head, T1, and head relative to T1 linear and angular displacements for females and males in this study. In comparison to the males the females had:

- lower and earlier peak x-displacements of the head, T1, and head relative to T1.
- lower and earlier peak angular displacement of the head and T1.
- more pronounced rebound motion, with an earlier return to their initial position and a larger forward x-displacement/flexion at the end of the data set, for the head and T1.

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