ABSTRACT

Objectives. The aim of the study was to measure and analyze backset, defined as the horizontal distance between the back of the occupant’s head and a point located on the ventral/top aspect of the sewn rim of the head restraint, with the car stationary and during driving, in the driver’s position in a modern car.

Methods. A population of 65 subjects, 35 males and 30 females, was studied in a Volvo V70 car, year model 2007. The subjects were studied in the driver’s position, in a self-selected posture. Stationary backset was measured with the technique described by (Jonsson et al., 20007), and backset during driving with video analysis. Descriptive data were calculated, and variability and correlation analyses were performed. A t-test was used to test differences of means. Significance level was set to 0.05.

Results. In comparison to stationary backset, mean backset during driving was 43 mm greater in males and 41 mm greater in females. Driving backset was 44 mm larger in males than in females. Driving backset was moderately correlated (0.37–0.43) to stature, seated height, and seat back angle in males, and moderately correlated (0.44-0.52) to hip width, waist circumference, and weight in females. The overall intraclass correlation coefficient for backset during driving was 0.81 (CI: 0.75-0.86).

Conclusions. These results may be of use in designing future updates of test protocols/routines for geometric backset, such as RCAR and RCAR-IIWPG.
INTRODUCTION

Rear end crashes often occur in urban areas with normal or dense traffic. Nearly half of all urban crashes in the US occur at intersections. In 2005, an estimated 1.9 million urban crashes occurred at intersections or were deemed to be intersection-related. Of these crashes, 52% occurred at traffic signals and another 22% at stop signs (HLDI, 2006). The crashes often take place in or on the approach to intersections, but they also occur on roads with queues and congestion (Andreasen et al., 1996; Dolinis, 1997; Navin et al., 2000; Söderström, 2004; Wang et al., 2003). According to a Swedish study by Söderström (2004), 78% of intersection crashes take place at traffic signals or other stop or yield signs. Inattention error contributes to 74% of the rear-end crashes, and driving too closely to 24% (Balock et al., 2005). In most cases (75–92%) of rear-end impact, the struck car is stationary (Balock et al., 2005; Söderström, 2004). Retting et al. (1995), who studied stopped or stopping crashes in four cities in the US, found that prior to or during the impact the cars which were struck had stopped or were stopping due to traffic lights or signs (31%), congestion (15%), preparing to turn (4%), or for other reasons (23%). This means that rear-end impacts take place at different locations, and occur both with the car stationary and during driving.

Increased backset (horizontal distance between the head restraint and the back of the head) has been reported to be associated with an increased risk of neck injury (Carlsson et al., 1985; Chapline et al., 2000; Farmer et al., 1999; Jakobsson et al., 1994; Olsson et al., 1990). Real world backset values depend on several factors such as seat design and settings, occupant size, and driving demands. We have already analyzed stationary backset in relation to occupant size and seat settings in our previous studies (Jonsson et al., 2007; 2008).

The aim of the present study was to study the relationship between stationary backset and backset during driving, while seated in the driver’s seat under different driving conditions in a high-rated safety car.

METHODS

Subjects

Subjects were recruited from the community of Örnsköldsvik, by advertising in the local newspaper and on a number of local company intranets. The inclusion criteria were: a valid class *B**** driving license; pain-free neck, thoracic, and shoulder regions; and age ≥ 18 years.

In total, 65 subjects (35 men and 30 women) participated in the study. The mean age was 46 (standard deviation (SD)=13 years) among the men, and 41 (SD=11 years) among the women. The average stature and weight were 180.8 cm (SD=8 cm) and 90.6 kg (SD=18 kg) for men, and 166.8 cm (SD=6 cm) and 71.8 kg (SD=15 kg) for women. In 2004–2005, the average stature and weight among the whole Swedish population aged 16–84 were 179.5 cm and 82.4 kg for men, and 165.5 cm and 66.6 kg for women, so our test subjects were almost identical in stature to the national average, but 5-8 kg heavier (SCB report, 2007).

Anthropometric data were measured on the subjects: stature, weight, seated height, waist circumference (level of umbilicus), and hip width (Pheasant, 1996). The subjects were given oral and written information about the test before giving their consent to participate in the study.
**Equipment**

The test car was a standard Volvo V70, model year 2007, designed for the Swedish market and equipped with Volvo’s electrically controlled driver’s seat.

The head restraint was removed from each seat (see Figure 1) before the subjects entered the car. A measuring device was constructed from two metal rods with an upper grade scale in between. The measurement points are shown in Figure 2. The horizontal distance was calculated mathematically. The intrapersonal measuring precision in reading the grade scales was less than ±0.5 degrees, leading to a possible measuring error of ±2 mm in each direction.

![Subject in driver’s position, with measurement equipment.](image)

A laser pointer was used to help the subjects perform cervical retraction with minimal horizontal and vertical deviation. The laser pointer was adjustable with the aid of a head strap and a compass housing (see Figure 1).

**Test procedure**

The test car was parked perpendicularly to and 3 meters away from a brick wall, with the front of the car facing the wall. Seated in the driver’s position, subjects were instructed to adjust the seat in a way they found comfortable (self-selected posture). They could also adjust the steering wheel, both vertically and in axial length, if desired. Finally they were asked to place their hands on the steering wheel in a “10 minutes past 10” position (see Figure 1).

**Measurement points and procedure**

The measurement points are shown in Figure 2. The reference point on the subjects was the occipital protuberance (1.) at the back of the head. Horizontal and vertical distances were measured with reference to a fixed zero-point on the frontal aspect of the seam of the fabric (2.) on top of the head restraint. The vertical line passing through point (2.) was 40 mm to the rear of the most frontal/central point of the saddle-shaped head restraint (4.).
Subjects were asked to identify a point on the brick wall in front of the car corresponding to the point where they would focus while driving, and the test leader adjusted the laser pointer to focus on this point. Subjects were instructed to keep the laser point still on the brick wall during the test.

Stationary measurements
With the car stationary, backset and cervical retraction capacity were measured in driver seat with the same technique and methods as utilized by Jonsson et al. (2007). Backset measurements were taken for the self-selected posture. Next, the test leader manually fixated the Th1 spinal level — see (3.) in Figure 2 — and subjects performed a maximal pain-free cervical retraction while keeping the laser point steady (maximum deviation of ±10 cm or 2 degrees).

Driving measurements
Before driving, the measuring device and head strap were removed and the head restraint reinstalled in its normal position in the driver’s seat. Each subject then drove along four routes, within and around the Swedish town of Örnsköldsvik (28 000 residents). The subjects were instructed to drive legally and normally according to the current traffic situation. The routes had different driving environments:

Figure 2. Location of measuring points: 1. occipital protuberance, 2. zero-reference point on head restraint located on the ventral/top aspect of the sewn rim, 3. Th1 spinal segment, 4. horizontal distance of 40 mm.
Route 1. Mainly motorway with a speed limit of 90 km/h, as well as a short distance with a limit of 70 km/h; no give way intersections.

Route 2. Major road with a few give way intersections, speed limit 70 km/h.

Route 3. Urban traffic with many give way intersections, speed limit 50 km/h.

Route 4. Highway with a few give way intersections, speed limit 50 km/h.

During driving, backset was recorded every 10 seconds for 5 minutes’ driving on each route, giving a total of 120 registrations per subject. At each stop between the routes, the seat position was recorded before being reset by the test leader into its most rearward, lowest, and most reclined position. The subjects were then asked to adjust it as they preferred and adopt their preferred seated posture (self-selected posture) before starting driving on the next route.

**Equipment**

Backset was analyzed using an onboard video camera, a Panasonic NV-GS500 with a Panasonic VW-LW4307ME wide conversion lens. The video film was stored in a Compaq nc6000 laptop and analyzed with Dartfish Connect software, version 4.0.9.0 (available at www.dartfish.com). The measurement length reference was a 300 mm long strip attached above the subject’s head. A horizontal strip was mounted as a reference on the side window to ensure correct video camera alignment. The horizontal distance between the zero-reference point (same as for stationary measurement) on the head restraint and the nose tip of the subject was measured at all 120 registrations (Figure 3). The horizontal sagittal depth of the subject’s head (back of head to tip of nose) was measured while seated in the car after finishing driving all four routes. This value was then subtracted from the driving data (which was measured from the nose tip) to give the subject’s actual driving backset.

![Figure 3. Horizontal measurement between zero-reference point and subject’s nose tip.](image)

**Data analysis**

Means and standard deviations were calculated for all descriptive data. An independent t-test was used to test differences in mean backset and cervical retraction between the sexes and in different seated postures. A paired t-test was used to test differences between backset while...
driving on the four routes and while stationary. Intraclass correlation coefficients (ICC) were calculated in order to study intra-individual variation in backset during driving. Pearson correlation between driving backset and anthropometric and seat adjustment data was calculated separately for both sexes. Pearson correlation was also calculated between stationary backset and backset during driving. The significance level was set to 0.05. Statistical analysis was performed using the SPSS software package (version 15.0).

RESULTS

Backset and cervical retraction – Stationary

With the car stationary, the subjects performed cervical retraction while seated in the driver’s seat with the head restraint removed. The retraction was performed in three postures: i) slouching, ii) self-selected, and iii) erect posture. The same retraction and measurement methods were used as in our earlier study (Jonsson et al., 2007).

Table 1. Mean backset and cervical retraction in driver’s position for males and females in a stationary car. Standard deviations are shown within brackets. Independent p-values are calculated between the sexes in each posture.

<table>
<thead>
<tr>
<th>Posture - Sex</th>
<th>Backset (SD) mm</th>
<th>p-value</th>
<th>Retraction (SD) mm</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erect - Male</td>
<td>37 (25)</td>
<td>&lt;0.001</td>
<td>22 (19)</td>
<td>0.260</td>
</tr>
<tr>
<td>Erect - Female</td>
<td>-2 (22)</td>
<td></td>
<td>25 (10)</td>
<td></td>
</tr>
<tr>
<td>Slouched - Male</td>
<td>112 (44)</td>
<td>&lt;0.001</td>
<td>29 (12)</td>
<td>0.362</td>
</tr>
<tr>
<td>Slouched - Female</td>
<td>63 (31)</td>
<td>&lt;0.001</td>
<td>27 (11)</td>
<td></td>
</tr>
<tr>
<td>Self-selected - Male</td>
<td>74 (34)</td>
<td>&lt;0.001</td>
<td>37 (11)</td>
<td>0.913</td>
</tr>
<tr>
<td>Self-selected - Female</td>
<td>32 (22)</td>
<td></td>
<td>37 (13)</td>
<td></td>
</tr>
</tbody>
</table>

Backset – stationary and during driving

Females

Table 2. Mean female backset while driving routes 1-4 and while stationary (self-selected posture); standard deviations and p-values.

<table>
<thead>
<tr>
<th></th>
<th>Backset</th>
<th>SD</th>
<th>Route 1 p-value</th>
<th>Route 2 p-value</th>
<th>Route 3 p-value</th>
<th>Route 4 p-value</th>
<th>Stationary p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route 1</td>
<td>66</td>
<td>22</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>Route 2</td>
<td>71</td>
<td>22</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
<td>p=0.534</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>Route 3</td>
<td>85</td>
<td>29</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>Route 4</td>
<td>70</td>
<td>23</td>
<td>p&lt;0.001</td>
<td>p=0.534</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>Stationary</td>
<td>32</td>
<td>22</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

There were significant differences between female backset means, with the exception of between routes 2 and 4. Figure 4 shows the relation between female stationary and driving backset.
Figure 4. Stationary backset and mean driving backset on routes 1-4, for females. Correlation coefficients (r) and significance values.

Mean driving backset was 66 mm (SD=22 mm) for route 1; 71 mm (SD=22 mm) for route 2; 85 mm (SD=29 mm) for route 3; and 70 mm (SD=23 mm) for route 4. Driving backset was 35-53 mm greater than mean stationary back set, with a mean of 41 mm. Correlation coefficients ranged from r = 0.47 to r = 0.60, with a mean of r = 0.58.

Males

Table 3. Mean male backset while driving routes 1-4 and while stationary (self-selected posture); standard deviations and p-values.
There were significant differences between male backset means, with the exception of between routes 2 and 4. Figure 5 shows the relation between male stationary and driving backset.
Figure 5. Stationary backset and mean driving backset on routes 1-4, for males. Correlation coefficients (r) and significance values.

Mean driving backset was 104 mm (SD=39 mm) for route 1; 114 mm (SD=40 mm) for route 2; 132 mm (SD=48 mm) for route 3; and 118 mm (SD=43 mm) for route 4. Driving backset was 30-58 mm greater than mean stationary backset, with a mean of 44 mm. Correlation coefficients ranged from r = 0.72 to r = 0.76, with a mean of r = 0.75.

**Backset – variability during driving**

The overall intraclass correlation coefficient (ICC) was 0.81 (95% CI: 0.75-0.86), indicating that most of the total variation in driving backset was found between the individuals. Males had a higher ICC (0.79; 95% CI: 0.71-0.86) than females (0.64; 95% CI: 0.53-0.77), indicating that females showed a greater intrapersonal variability during driving. Box plots of individual standard deviations are shown in Figure 6, to illustrate the individual variation. Males had larger median standard deviation. The results show that variability was greater for males on all routes except route 3.

![Box plots of standard deviation for males and females driving the four routes (sd1-4) in mm. Outliers are marked as ° and *.

Figure 6. Median, Q1, Q3, and smallest and largest observations of standard deviation for males and females driving the four routes (sd1-4) in mm. Outliers are marked as ° and *.](image-url)
Factors correlated with driving backset

Backset while driving the four different routes may have been affected by seat adjustments and anthropometrical variables, and so we performed bivariate correlation analysis on these variables. Among females, there was significant correlation (0.52, p=0.003) between body weight and backset. Waist circumference (0.45, p=0.012) and hip width (0.44, p=0.015) were also correlated with female driving backset. Among males, stature (0.38, p=0.023) and seated height (0.42, p=0.013) were both correlated with backset, as was seat back angle for all routes except route 2. Seat back angle correlation coefficients were 0.37 for route 1 (p=0.028), 0.43 for route 3 (p=0.009), and 0.39 for route 4 (p=0.021), indicating a moderate correlation between inclination of the back support and male backset during driving.

DISCUSSION

In this study, we chose to measure backset in a car with a seat and head restraint of good geometric design, the Volvo V70 (IIHS, 2007). The use of several different cars with a high safety rating may have given a more complete picture, but due to the nature of the study this would have been very expensive and very time consuming for the subjects. The current test design required 1.5 hours per subject.

This study has some limitations. Measuring backset on taller occupants increases the risk of parallax error, especially when using wide lens optics. The measuring accuracy of backset during driving was set to ± 5 mm after manual control measurements of backset with the seat in its most forward and rearward longitudinal position. In addition, some of the subjects were not used to driving a car with an automatic gearbox, and this may have affected the results. Even though the measurement accuracy is not exact, as described above, it is still an improvement on previous studies (Parkin et al., 1995).

Backset

Rear-end impacts occur on both stationary and moving cars. There is a great deal of existing data on stationary backset, due to the use of BioRID manikins in crash testing. The Insurance Institute for Highway Safety (IIHS) is an independent organization which rates car seats and head restraint designs with respect to rear-end impacts. The IIHS test consists of two parts: i) geometrical evaluation; and ii) a dynamic crash test, which is conducted if and only if the geometrical evaluation test is passed. In both parts of the test, the BioRID manikin is used as an occupant surrogate. Backset during driving in traffic was studied by (Parkin et al., 1995), who measured 1000 drivers (742 males and 237 females) and found at that at the 50-percentile level, females had 62 mm lower backset compared to males. However, seat geometry has developed further in the years since this study, and so it is important to collect more and newer data regarding backset during driving. Among males in the present study, mean driving backset was 117 mm (SD=41 mm; range 104-132 mm; see Table 3), and was 43 mm larger than stationary backset. Among females, mean driving backset was 73 mm (SD=23 mm; range 66-85 mm; see Table 2), and was 41 mm larger than stationary backset. The difference between stationary and driving backset was independent of sex, and probably due to visual needs during driving. The study also showed that in both males and females there was a mean driving backset difference of 44 mm (range 38-48 mm) between the routes. Mean stationary backset difference was 42 mm. As demonstrated in Figure 4 and 5, mean correlation between stationary and driving backset was stronger for males (r = 0.75) than for females (r = 0.58).
Driving on the urban route (route 3) led to higher backset values for both males and females in comparison to the other routes, and variability was also highest on this route, particularly for females (see Figure 6). These results are probably the result of increased vision demands during driving, but the sex difference is harder to explain. It is possible that females check more carefully at intersections. In this study, we had no knowledge of driving experience among the subjects. The other routes showed smaller but still significant differences, with the exception of routes 2 and 4 for both sexes, where the differences between the mean backset values were not significant.

Driving backset was significantly correlated to other factors, though the correlations were only moderate (Cohen, 1988), ranging between 0.37 and 0.52. Male backset was correlated to stature, seated height, and back seat angle. Increased backset was also found to be significantly related to increased driver stature in our previous study, which used a different and larger (n=78) study sample (Jonsson et al., 2007). We have also previously shown a back angle difference of 3 degrees between the sexes (Jonsson et al., 2008), while in the present study males sat 4 degrees more reclined than females. Increased female backset was correlated with increased weight, waist circumference and hip width, indicating that female posture is affected by the anthropometrical constitution of the hip/waist region. This is important from a seat design point of view.

Finally, mean cervical retraction capacity in the self-selected driver position was 37 mm (SD=12 mm) for both males and females. Slouched posture resulted in a mean capacity of 28 mm (SD=12 mm) and erect posture in a mean capacity of 24 mm (SD=12). In a previous study (Jonsson et al., 2007), we used the same measuring technique. The results showed the same pattern of range of movement, but with values that were 2–4 mm lower. There were no significant differences between the sexes for each posture. The findings in the present study regarding self-selected posture were slightly higher than found by previous researchers (Brault et al., 1998, Edmondston et al., 2005, Jonsson et al., 2007), who reported a range of 29-35 mm. The mean driving backset of 117 mm (male) and 73 mm (female) should be reduced by 40 mm (see Figure 2) to obtain the distance from the most ventral aspect of the head restraint, giving a mean driving backset of 77 mm for males and 33 mm for females. Given these data, there might be a risk of end-range loading of cervical joints in rear-end collisions for subgroups of occupants such as tall males and perhaps taller females. Taller occupants of both sexes are a subgroup that has increased risk for initial AIS 1 neck injury in rear-end impacts (Jakobsson, 2005).

The results of this study may be of use in designing future updates of test protocols/routines for geometric backset, such as (RCAR, 2001; RCAR-IIWPG, 2006).

CONCLUSIONS

1. Mean driving backset was larger than stationary backset; the difference was 43 mm in males and 41 mm in females.
2. Mean driving backset was 44 mm larger in males than in females.
3. Males showed a fairly strong mean correlation between stationary and driving backset (r = 0.75). Females had a lower mean correlation (r = 0.58).
4. Males showed a moderate correlation (0.37-0.43) between driving backset and stature, seated height, and seat back angle (except on route 2).
5. Females showed a moderate correlation (0.44-0.52) between driving backset and hip width, waist circumference, and weight.
6. Urban driving produced a larger backset for both sexes compared to driving in more rural conditions.

ACKNOWLEDGMENTS

This study was financed by grants from Skytfonden, a subsidiary branch of Vägverket (Swedish Road Administration), and Autoliv Research Sweden. The authors would also like to thank all personnel at Bilprovningen (Swedish Motor Vehicle Inspection Company) in the city of Örnsköldsvik for their kind and helpful assistance.

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