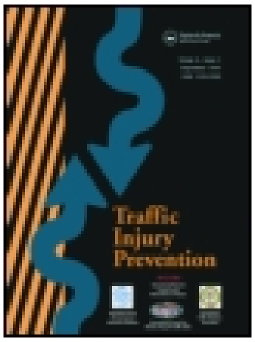

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Real-world adjustments of driver seat and head restraint in Saab 9-3 vehicles

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ABSTRACT

Objective: Whiplash-associated disorder (WAD), commonly denoted whiplash injury, is a worldwide problem. These injuries occur at relatively low changes of velocity (typically <25 km/h) in impacts from all directions. Rear impacts, however, are the most common in the injury statistics. Females have a 1.5–3 times higher risk of whiplash injury than males.

Improved seat design is the prevailing means of increasing the protection of whiplash injury for occupants in rear impacts. Since 1997, more advanced whiplash protection systems have been introduced on the market, the Saab Active Head Restraint (SAHR) being one of the most prominent. The SAHR—which is height adjustable—is mounted to a pressure plate in the seatback by means of a spring-resisted link mechanism.

Nevertheless, studies have shown that seats equipped with reactive head restraints (such as the SAHR) have a very high injury-reducing effect for males (∼60–70%) but very low or no reduction effect for females. One influencing factor could be the position of the head restraint relative to the head, because a number of studies have reported that adjustable head restraints often are incorrectly positioned by drivers.

The aim was to investigate how female and male Saab drivers adjust the seat in the car they drive the most.

Methods: The seated positions of drivers in stationary conditions have been investigated in a total of 76 volunteers (34 females, 42 males) who participated in the study. Inclusion criteria incorporated driving a Saab 9–3 on a regularly basis.

Results: The majority of the volunteers (89%) adjusted the head restraint to any of the 3 uppermost positions and as many as 59% in the top position.

The average vertical distance between the top of the head and the top of the head restraint (offset) increase linearly with increasing statures, from an average of −26 mm (head below the head restraint) for small females to an average of 82 mm (head above the head restraint) for large males. On average, the offset was 23 mm for females, which is within a satisfactory range and in accordance with recommendations; the corresponding value for males was 72 mm.

The backset tended to be shorter among female volunteers (on average 27 mm) compared to the male volunteers (on average 44 mm). Moreover, the backset tended to increase with increasing statures.

Conclusions: Incorrect adjustment of the head restraint cannot explain the large differences found between the sexes in the effectiveness of the SAHR system.

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Introduction

Whiplash-associated disorder (WAD), commonly denoted whiplash injury, is a worldwide problem. These injuries are costly because they are frequent and can lead to long-lasting pain and disability. In Europe, the annual cost for whiplash injuries has been estimated at €10 billion (Richter et al. 2000). In the United States, the annual number of whiplash injuries has been estimated at 800,000, of which 270,000 resulted in rear impacts with an associated annual cost of $2.7 billion (NHTSA 2004). In Japan, 547,654 traffic-related (vehicle) occupant injuries were registered during 1996, of which 44% were neck injuries (Watanabe et al. 2000). Whiplash injuries account for 50% of all crash-related injuries leading to permanent medical impairment (Krafft 1998; Kullgren et al. 2007). The majority of those experiencing initial neck symptoms following a car crash recover within a few weeks or months of the crash (The Whiplash Commission 2005). However, 2–16% of individuals do experience permanent medical impairment of varying degrees (Galasko et al. 1996; Malm et al. 2008; Nygren 1984; The Whiplash Commission 2005). These injuries occur at relatively low changes in velocity (typically <25 km/h; Eichberger et al. 1996; Kullgren et al. 2003) and in all impacts directions. Rear impacts, however, are the most common in the injury statistics (∼50% of all cases; Stigson et al. 2015). Reviewing previous studies, it was found that the whiplash injury risk is 1.5–3 times higher in females than in males (A. Carlsson et al. 2012).

Improved seat design is the prevalent means of increasing whiplash injury protection for occupants during a rear impact. The strategy is to minimize the relative motion of the head and torso—that is, to reduce the relative motion between each spinal

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segment—and to reduce acceleration and rebound motion. This can be accomplished by improving seat geometry and dynamic properties of the head restraint and seatback; through active devices that move in a crash as the body loads the seat; and by energy absorption in the seat. Since 1997, more advanced whiplash protection systems have been introduced on the market. The relative risk of sustaining a whiplash injury leading to long-term symptoms is approximately 40% lower in cars fitted with more advanced whiplash protection systems in the seats than in cars with standard seats launched after 1997 (Kullgren et al. 2013). Compared to cars with standard seats, launched before 1997, the difference is even greater.

One of the most prominent whiplash injury reduction systems is the Saab Active Head Restraint (SAHR; Wiklund and Larsson 1998). It was introduced 1997 (early 1998 in the United States) in the 9–5 model as a first application of crash-activated systems to mitigate whiplash injuries. The active head restraint—which is adjustable in height—is mounted to a pressure plate in the seatback by means of a spring-resisted link mechanism (Figure A1, see online supplement). When the seat pushes the occupant forward with more force than the spring can resist, the plate moves rearward into the seat. This forces the head restraint to move upward and forward, thus supporting the head before the relative motion between the head and the torso becomes significant (Wiklund and Larsson 1998). In addition to the active head restraint, the SAHR system includes design features in the seatback to control and distribute loads generated in rear impacts on the occupant (Wiklund and Larsson 1998).

Overall data from the Swedish car fleet reveal that existing whiplash protection concepts in general are more effective for males than females, with a 31% risk reduction of permanent medical impairment for females and 52% for males, according to insurance claims records (Figure 1a; Kullgren et al. 2013). However, substantial differences were found when analyzing the different whiplash protection concepts separately (Figures 1b–1c; Kullgren et al. 2013). Seats designed to absorb energy in the seatback (such as passive seats and Whiplash Protection System or WHIPS) had equal or even somewhat higher effectiveness for females compared to males (also shown in Jakobsson and Norin 2004), while seats with reactive head restraints (RHR, such as SAHR) showed very high reduction effects for males (60–70%) and very low or no reduction effects for females (Kullgren et al. 2013). Thus, the RHR systems, focusing on geometric performance initially in the crash phase, appear to have a limited effect on the protection of women.

One potential influencing factor is the position of the head restraint. The effectiveness of head restraints improves the higher (Chapline et al. 2000; Farmer et al. 1999; Nygren et al. 1985) and closer to the head of the occupant (Olsson et al. 1990) they are positioned. A low head restraint position may increase the whiplash effect by acting as a fulcrum, whereas more support of the head improves performance (Berton 1968; Severy et al. 1967, 1968). Ono and Kanno (1996) recorded the greatest neck extensions and lowest loads when the head restraint was not installed, whereas the greatest neck loads were registered when the head restraint was adjusted in a low position. The best effect was observed when the head restraint was adjusted in a high position. Chapline et al. (2000) reported that the head restraint height was the primary factor related to head restraint

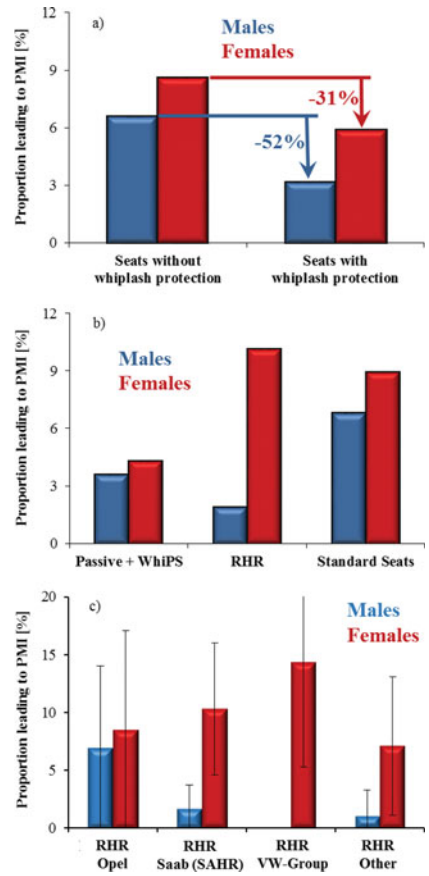

Figure 1. Proportion of initial whiplash injuries, leading to permanent medical impairment (PMI) in seats of model year >1998 (a) with and without whiplash protection; (b) in passive whiplash protection systems (including WHIPS), RHRs, and standard seats; and (c) in different RHR concepts, for females (red bars) and males (blue bars). Based on Kullgren et al. (2013).

effectiveness, especially in females (Figure A2, see online supplement). Although it was not statistically significant for male drivers, the percentage of both female and male drivers reporting neck pain increased the lower the position of the head restraint was below the head's center of gravity. Viano (2008, p. 552) concluded that "large forces can be applied to the occupant once the head, neck, and torso are supported by the seat and head restraint without adverse loading of the spine."

A number of studies have reported that adjustable head restraints often are incorrectly positioned, either based on the average head restraint height relative to standards, current at the time of publication, or in relation to the occupant for whom they were adjusted (Cullen et al. 1996; Garrett and Morris 1972; Insurance Institute for Highway Safety [IIHS] 1995; Kahane 1982; Lubin and Sehmer 1993; Nygren et al. 1985; Viano and Gargan 1996; Young et al. 2005). For example, Nygren et al. (1985) reported that 83% of adjustable head restraints were positioned in the lowest or second lowest setting during regular driving conditions; Garrett and Morris (1972) found 73% of adjustable head restraints in the down position; and Viano and Gargan (1996) found that 76% of adjustable head restraints were positioned in the lowest possible configuration. Similarly, Viano and Gargan (1996) reported that the head restraint geometry in 91% of cases would have benefited from being positioned higher relative to the head of the driver, and Cullen et al. (1996) demonstrated that 88% of car users had adjusted the head restraints too low to benefit from any protection against whiplash injury. The latter study also showed that the vertical separation between the head and head restraint in female car occupants was shorter. This is likely due to males being typically taller than females (IIHS 1995).

More information is needed regarding the head restraint position in real-world situations to further understand the reason for the reported differences in effectiveness of the Saab SAHR system for females and males. Thus, the aim of this study was to investigate how female and male Saab drivers adjust their seats in the car they normally drive.

Methods

A study with the purpose of examining seated postures and seat adjustments of drivers has been conducted in stationary conditions. The participants were males and females of different age, stature, and mass. In order to obtain results that are as realistic as possible, the participants brought their own cars. To minimize the risk of particpants adjusting the settings in their car differently than they would normally, they only received sparse information about how the study would be executed.

Volunteers

Seventy-six volunteers—34 females and 42 males—participated in the study. The inclusion criterion for all volunteers was to drive a Saab 9–3 on a regular basis. If there was more than one person driving the same car regularly, they were also welcome to participate in the study. Of the 76 volunteers, 30 appeared alone and 46 were accompanied by at least one other volunteer. In cases when volunteers shared the same vehicle, 60% of the cars were driven to the test site by male drivers.

The average age of the volunteers was 49 years (SD = 19 years). With regards to their stature, all volunteers were matched to a size category according to the 4 sizes selected in the study of Schneider et al. (1983); the 5th (151.1 cm) and 50th (161.8 cm) percentile females and the 50th (175.3 cm) and 95th (186.9 cm) percentile males. With this definition in mind, the female volunteers were categorized into 3 different sizes; 3 “small females” (closest to the 5th percentile female), 16 “mid-sized females” (closest to the 50th percentile female), and 15 “large females” (closest to the 50th percentile male). Similarly, the male volunteers were categorized into 2 different sizes; 20 “mid-sized males” (closest to the 50th percentile male) and 22 “large males” (closest to the 95th percentile male; Table A1, see online supplement). The stature distribution of the volunteers reflects the stature of the general population in Sweden (females: average stature 166.2 cm; males: average stature 180.0 cm; Hanson et al. 2009), which may explain the low numbers of small females ($n = 3$) and males ($n = 0$) participating in the study.

The volunteers were recruited in 2 different ways. The majority ($n = 57$) were recruited through an invitation letter that was sent to owners of the specific car model in the Gothenburg area. The addresses were extracted from the Swedish national register of car owners, kept by the Swedish Transport Agency. In total 550 letters were sent, with a link to a booking schedule in Google Forms (which achieved a response rate of 10.4%). The other volunteers ($n = 19$) were recruited in parking lots in the Gothenburg area. The researchers waited in parking lots and approached occupants of the surveyed car model to find out whether they were willing to participate in the study right there and then. Each participant received 2 cinema tickets as reimbursement after the measurements were taken.

Table 1. There are 2 different versions of HRs in the Saab 9–3, model years 1998–2002. The HR position 100% equals the upmost position of the HR for both models. The HR position 0% equals the lowest position of the HR in the new model, whereas −80% equals the lowest position in the old model.

	HR height		HR settings	
	(%)	(mm)	Old model	New model
Only the old model	−80	−44.8	1(10)	—
	−60	−33.6	2(10)	—
	−40	−22.4	3(10)	—
	−20	−11.2	4(10)	—
Same for the old and new models	0	0	5(10)	1(6)
	20	11.2	6(10)	2(6)
	40	22.4	7(10)	3(6)
	60	33.6	8(10)	4(6)
	80	44.8	9(10)	5(6)
	100	56.0	10(10)	6(6)

Old model (10 height settings) New model (6 height settings)

Car model

Five-door Saab 9–3s, model years 1998–2002, with manually adjustable seats, were chosen for this study (Aero/Viggen/coupe/cabriolet/sport models were excluded). The front seats of this car model are equipped with the SAHR Generation I whiplash protection system (Wiklund and Larsson 1998). The volunteers brought their own car, in which all measurements were made.

In this car model the head restraint can be adjusted upwards simply by pulling it; however, to adjust it downwards a small release button has to be pressed while pushing the restraint down. Thus, it is easier to adjust the head restraint upwards (one-hand operation) than downwards (2-hand operation). Depending on the model year, there are 2 different versions of the head restraint for the specific car model (Table 1). The difference between the restraints is that the older version has 10 distinct height settings instead of 6. The 6 highest settings are identical for the 2 different models, whereas the older model has 4 extra lower positions.

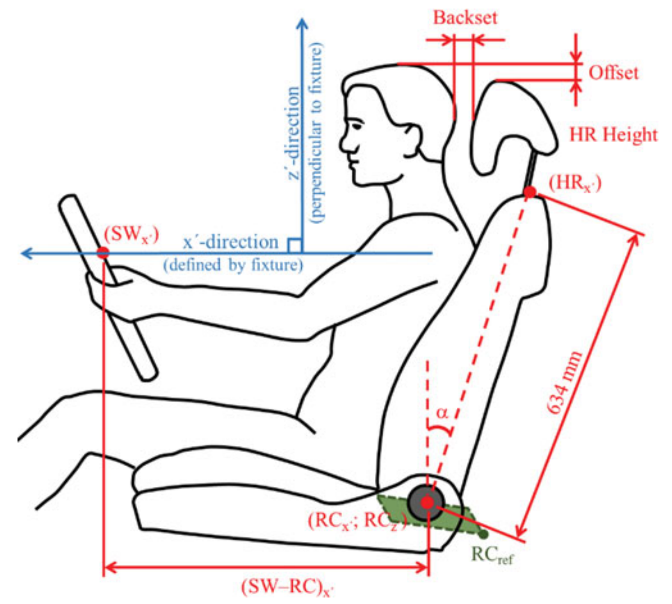

Figure 2. The test setup. The reference point—RC_{ref}—was defined by the recliner center when the seat was adjusted as far back and as low as possible.

The driver seat is adjustable in the horizontal direction (total range 203 mm), as well as in the vertical direction (total range 58 mm). The seatback angle is changed by turning the seatback adjuster on the outboard side of the seat. Moreover, the steering wheel position can be adjusted along the steering column axis by releasing a lever under the steering wheel and then either pushing it in or pulling it out. When a comfortable position has been achieved the lever must be secured again.

Procedure

Firstly, the volunteers were instructed to park on a level parking lot and lower the front side window before turning off the engine. The volunteers were then asked to position themselves in the seated posture they would generally adopt while driving in urban areas, face forward, and place their hands on the steering wheel in a commonly used position. The following parameters were measured/registered (Figure 2):

- Backset—The shortest horizontal distance between the head and the head restraint. This distance was measured using a caliper.
- Offset—The vertical distance between the top of each volunteer's head and the top of the head restraint.
- HR height—The height adjustment of the head restraint.

Secondly, the volunteers were instructed to step out of the car, without adjusting any seat settings, and close the door. A measurement fixture was passed through the open window and placed on top of the window frames between the driver's door and the front passenger's door, aligned with the lock buttons; details about the procedure are specified in the online supplement (including Figures A3–A4, see online supplement). The following parameters were measured/registered (Figure 2):

- $RC_{x'}$—The horizontal position of the recliner center.
- $RC_{z'}$—The vertical position of the recliner center.
- $HR_{x'}$—The horizontal position of the head restraint, measured at the entrance of the head restraint inserts.
- $SW_{x'}$—The horizontal position of the steering wheel (in the plane defined by the top surface of the fixture).

Thirdly, the volunteers were asked whether they found the seated posture comfortable while driving and any comments were noted. Furthermore, they were asked about their stature, mass, and age and their answers were registered. Thereafter the session was ended.

If more than one person joined the study, she or he was asked to adjust the seat and steering wheel as she or he normally would before driving, followed by the same procedure, as described above.

Later, the following parameters were calculated based on the collected data (Figure 2):

- $(SW - RC)_{x'}$—The horizontal distance between the steering wheel and the recliner center.
- α—The seatback angle $= \arcsin((HR_{x'} - RC_{x'})/634)$.

Finally, the RC position was recalculated with regards to a reference point—RC_{ref}—defined by the recliner center at the point where the seat was adjusted as far back and as low as possible (Figure 2).

Results

The vast majority of volunteers (89%) adjusted the head restraint in any of the 3 uppermost settings, and as many as 59% had the head restraint in the top position (Table 2). The distributions were similar for the female and male volunteers, despite the shorter average stature of the females (females 168 cm; males 183 cm; Table 2; Table A2, see online supplement).

The vertical offset increased linearly with increasing statures, from an average of −26 mm (i.e., head below the head restraint) for the small females to an average of 82 mm (i.e., head above the head restraint) for the large males (Figure 3a; Table A2). The offset ranged from −52 to 85 mm among females and from 0 to 180 mm among males (Figures A5a and A6a, see online supplement).

The horizontal backset tended to be shorter among the female volunteers (on average 27 mm) compared to the male volunteers (on average 44 mm; Figure 3b; Table A2). However, there were large individual differences, from 0 to 105 mm for females and from 0 to 117 mm for males (Figures A5b and A6b, see online supplement). Moreover, the backset tended to increase with increasing statures (Figure 3b; Table A2).

The seatback angle, α, was approximately the same (∼20°) for the mid-sized and large females and males but considerable less for the small females (on average 12°; Figure 3c; Table A2). However, there were large differences between individuals, ranging from 9° (a small female) to 27° (a mid-sized female).

The distance between the recliner center and the steering wheel, $(SW - RC)_{x'}$, increased linearly with incresing statures, from an average of 413 mm for small females to an average of 520 mm for large males (Figure 3d; Table A2). Among individuals, the distance ranged from 362 mm (small female) to 589 mm (large male). In addition, the x'-position of the recliner center was in a linear relationship with the volunteers' size, from an average of 47 mm for the large male to 154 mm for the small female (Figure 3e; Table A2). Furthermore, large females and males tended to have the seat adjusted at lower z'-positions compared to drivers of smaller stature, however, the relationship

Table 2. HR height with regards to the size of small, mid-sized, and large female volunteers and mid-sized and large male volunteers.

						Distribution		
HR height	Small female	Mid-sized female	Large female	Mid-sized male	Large male	Females (%)	Males (%)	All (%)
−80%	—	—	—	1	—	—	2	1
−60%	—	—	—	—	—	—	—	—
−40%	—	—	—	—	—	—	—	—
−20%	—	—	—	—	—	—	—	—
0%	1	2	—	2	—	9	5	7
20%	—	—	—	—	—	—	—	—
40%	—	1	—	1	—	3	2	3
60%	—	3	2	2	2	15	10	12
80%	1	1	4	6	2	18	19	18
100%	1	9	9	8	18	56	62	59
Total	3	16	15	20	22	100	100	100

between the z'-position and stature was not linear (Figure 3f; Table A2).

In cases including more than one volunteer in the same car, it was noted that neither the position of the head restraint nor the position of the steering wheel was adjusted between individuals.

Of the 76 volunteers, 17 (11 females and 6 males) commented on the seated posture. These comments are summarized in the the online supplement.

Discussion

The aim of this study was to investigate how female and male Saab drivers adjust their seat in the car they normally drive; of particular interest was the position of the head restraint relative to the head. The volunteers were frequent drivers of the vehicle they were tested in, and it can therefore be assumed that they adjusted the seat as they usually would. The stature distribution of the volunteers reflects the stature of the general population in Sweden (i.e., the same population as the vehicle occupants in Figure 1). The overall purpose was to increase the understanding of the differences found in the effectiveness of (re)active head restraints between the sexes (Figure 1). If the SAHR system were as effective for females as it is for males, it has the potential to be the best whiplash protection system of all.

Each one of the volunteers was matched to a size category in accordance to the 4 dummy sizes selected in the study by

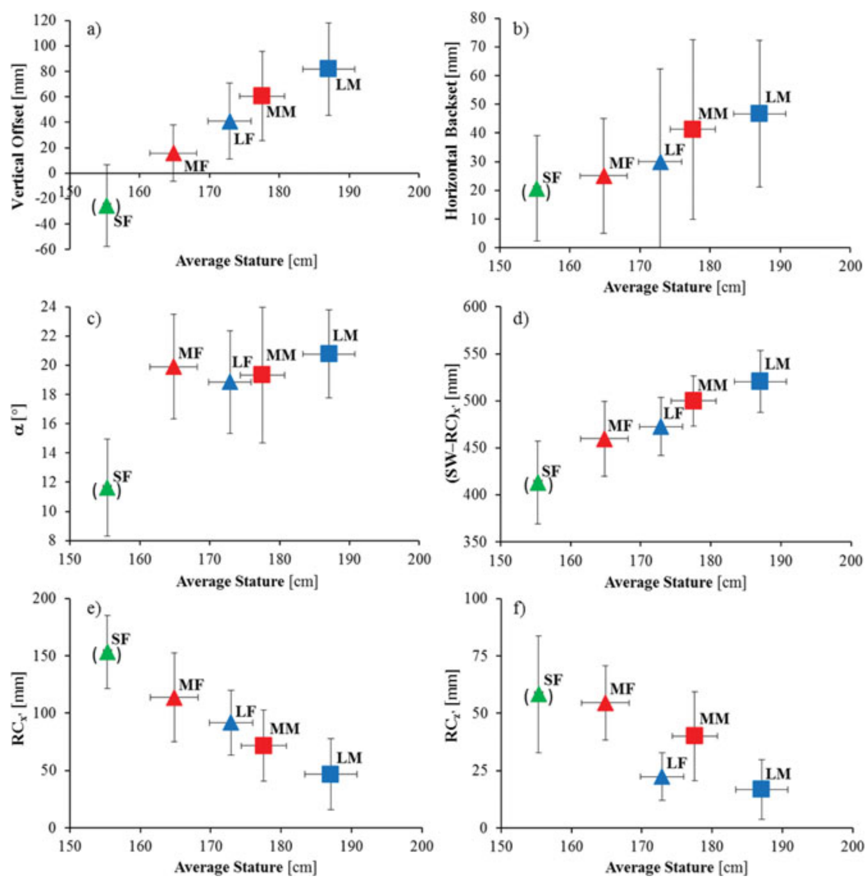

Figure 3. The (a) vertical offset, (b) horizontal backset, (c) seatback angle, (d) steering wheel-to-recliner center (RC) x'-distance, (e) RC x'-position, and (f) RC z'-position for small (SF), mid-sized (MF), and large (LF) female volunteers and mid-sized (MM) and large (LM) male volunteers. The error bars indicate ±1 SD. Parentheses around the green (SF) data point indicates that the corresponding value is based on data from only 3 individuals.

Schneider et al. (1983). Separating the data into these categories, specifically the 50th percentile female, provides more information that can be used in furthering the development of EvaRID (A. Carlsson et al. 2014).

The study revealed that a large majority of Saab drivers adjust the head restraint to a (very) high position (89% in any of the 3 uppermost positions and 59% in the top position). This contradicts previous studies reporting that drivers frequently adjust their head restraints too low (Cullen et al. 1996; Garrett and Morris 1972; IIHS 1995; Kahane 1982; Lubin and Sehmer 1993; Nygren et al. 1985; Viano and Gargan 1996; Young et al. 2005). The reason why so many of the Saab drivers adjust the head restraint at such high positions is probably due to the technical configuration of the locking mechanism, because it is easier to move the head restraint upwards (one-hand operation) and more complicated to adjust it downwards (2-hand operation). However, in older cars, the head restraints were generally not lockable and just as easy to adjust upwards as downwards (both one-hand operations)—which may explain the results of previous studies. Thus, due to improved locking mechanisms in recent-year model cars, adjustable head restraints are probably more likely positioned at higher positions compared to older models. Further studies are recommended.

The vertical offset was on average 23 mm for females and 72 mm for males (Table A2). Based on the RCAR rating of head restraints (Zuby and Lund 2010), 74% of females were rated good, 21% acceptable, 6% marginal, and 0% poor; the corresponding values for males were 24% good, 36% acceptable, 21% marginal, and 19% poor. Previous studies have shown that the effectiveness of head restraints improves as they are positioned higher relative to the head of the occupants (Nygren et al. 1985), especially in females (Chapline et al. 2000; Farmer et al. 1999). Thus, incorrect vertical adjustment of the head restraint cannot explain why the SAHR system does not provide as much protection for females as for males (Figure 1c).

The horizontal backset tended to be shorter for females (27 mm) compared to males (44 mm; Table A2), which confirms previous studies (Figure A7, see online supplement; A. Carlsson et al. 2011; Jonsson et al. 2007; Linder et al. 2008; Minton et al. 1997; Schick et al. 2008; Szabo et al. 1994). In general, a short backset is associated with lower whiplash injury risk (G. Carlsson et al. 1985; Deutcher 1996; Farmer et al. 1999; Jakobsson et al. 2004; Nygren et al. 1985; Olsson et al. 1990). A backset less than 10 cm was found to be more beneficial with regards to whiplash injury outcome compared to a backset greater than 10 cm. Based on mathematical simulations, Stemper et al. (2006) suggested limiting the head restraint distance to less than 6 cm, either passively or actively after impact, to further reduce the whiplash injury risk. In this study, 88% (97%) of females and 69% (92%) of males had a backset below 60 mm (100 mm); that is, the vast majority of females had a backset within the recommended limits. Thus, 60-mm backset may not be a sufficient condition to achieve good protection, at least not for females.

Based only on the static measurements of the present study, improper adjustment of the head restraint cannot explain the differences found between the sexes in the effectiveness of the SAHR system. Instead, the answer may be found in the seatback interaction and dynamic responses following a rear impact. Occupants with small anthropometry (typically females) may have different seatback interaction compared to occupants with large anthropometry (typically males; A. Carlsson 2012). Smaller occupants may to a greater extent interact with the interior seatback structures (such as springs, rods, lumbar support, and steel mesh), whereas larger occupants may interact more with the seatback frame. A smaller body size/shorter stature may potentially result in a deeper intrusion into the seatback (A. Carlsson 2012). In combination with a (re)active head restraint and a shorter backset, this may cause a forward push to the head, resulting in protraction of the neck rather than retraction. Furthermore, because the SAHR mechanism moves the head restraint in a forward/upward direction, it may potentially raise the head restraint too high for occupants of smaller sizes—especially because most of the females in this study had the head restraint adjusted to a very high position. This may result in the head restraint supporting the higher part of the back of the head, above the center of gravity, which may deviate from neutral support of the head/neck (which is not the case for males). This may be exacerbated by the adjustment mechanism, which makes moving the head restraint upwards easy and adjusting it downwards (to a position that may be better optimized for a shorter occupant) more difficult, as well as the fact that drivers of shared cars did not adjust their head restraints to fit themselves. Moreover, the deflection of the seatback frame, seatback padding, and springs may depend on the mass and/or the center of mass of the upper body with respect to the lever about the seatback hinge. The deflection of the seatback structures affects the plastic deformation, energy absorption, and dynamic head-to-head restraint distance, as well as the rebound of the torso (Croft et al. 2002; Svensson et al. 1993; Viano 2003). It has been reported that females have a somewhat different dynamic response in rear volunteer tests, such as greater head forward acceleration, greater (or similar) T1 forward acceleration, lower (or similar) Neck Injury Criterion values, and a more pronounced rebound than males (A. Carlsson et al. 2011, 2012; Croft et al. 2002; Hell et al. 1999; Linder et al. 2008; Mordaka and Gentle 2003; Ono et al. 2006; Schick et al. 2008; Siegmund et al. 1997; Szabo et al. 1994; Viano 2003; Welcher and Szabo 2001). A contributing factor behind the greater improvement in neck protection with SAHR for males compared to females may be that the SAHR offers improved vertical head restraint geometry for males, whereas the female geometry was adequately high already in the older seat designs. More research into the above issues is highly recommended.

Today, rear impact testing is performed with 50th percentile male dummies—mainly the BioRID II—which may limit the assessment and development of whiplash protection systems in regards to female occupant protection. Only the extremes of the female population are accounted for by the existing dummies that may be used for rear impact testing: the 50th percentile male rear impact dummy or, possibly, the 5th percentile female frontal impact dummy. Yet, females of average size are associated with the highest whiplash injury frequency in rear impacts (A. Carlsson et al. 2014; Kihlberg 1969).

Studies have indicated that there is no simple way to “reinterpret” or “scale” data obtained with the 50th percentile male BioRID dummy to address the female dynamic response (A. Carlsson 2012). Thus, it is important that future whiplash protection systems are developed and evaluated with consideration of female properties as well. Based on mathematical simulations, Mordaka and Gentle (2003) concluded that a "scaled down male model is not adequate to simulate female responses even though the scaling constitutes a good height and mass match" (p. 52). 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" (p. 114).

The results of this study stress the importance of further research and development of 50th percentile female occupant models.

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