Seat Belt Fit and Comfort for Older Adult Front Seat Passengers in Cars

Anna-Lisa Osvalder, Katarina Bohman, Magdalena Lindman, Robin Ankartoft, Svante Alfredsson

Abstract An explorative user study was performed to study seat belt fit, perceived comfort and safety awareness of older adults in the front passenger seat of a large, stationary passenger car. The study included 55 participants between 65 and 80 years (32 males, 23 females). The participants buckled up in two scenarios, in a pre-defined seat position and in a self-adjusted preferred seat position. Anthropometric measures, photographs, and measurements of seat and seat belt positions were taken. Interviews were conducted regarding comfort perception and previous awareness of seat belt usage and discomfort. The results showed a change in seat belt fit due to older adults' body compositions and increased BMI, and a limited safety awareness of non-optimal shoulder and lap belt fit. Some usually experienced discomfort in regular driving and used add-on accessories to increase sitting height and decrease sitting discomfort. These findings are important when designing restraint systems in future vehicles to ensure further improved safety for older adults.

Keywords older adults, seat belt fit, user study, comfort, safety awareness.

I. INTRODUCTION

With the increasingly aging population and the development of automated cars, an increasing number of elderly people will be travelling by car in the future. Today the estimated life expectancy in the Western world is 83 years [1], and in 2030 one in four persons will be over 65. Older adults are healthier today and engage in travel, social and health-promoting activities [2]. Mobility, comfort and safety are important issues for this generation [3]. They are frequent car users and accustomed to decide when and where, and how to travel.

The older population differs from the younger regarding musculoskeletal characteristics and physical abilities, for example body size, range of motion, joint flexibility, and skeletal and muscular strength [4-5]. Due to degeneration of the intervertebral discs decreased standing and sitting height occurs. Disc degeneration, together with muscle weakening and loss of elastic tissue in the ligaments also result in postural changes entailing a more forward-leaning posture [4]. Flatter and more kyphotic spinal curves, leading to a slumped posture, are observed for both men and women over 60. About 20-40% have fully developed kyphosis, i.e. an excessive convex spine curvature [4]. Thoracic kyphosis is associated with a forward head posture assessed via the craniovertebral angle (CVA), and a lesser CVA indicated greater forward head posture [6-7]. To conclude, the change in the muscular-skeletal system by age results in an altered posture, both in sitting and standing [8].

With age, redistribution of fat occurs, resulting in more fat, less muscle mass and an increased body mass index (BMI) leading to change in body shape and strength. Studies have shown increased upper and central body fat deposition with age for both men and women [9], others have shown that upper body obesity for those over 65 is more common among men than women [10]. However, there are age-related changes in the distribution of body fat that are not adequately captured by an increased BMI [11]. Older people are more fragile than younger and thereby have an increased risk of injury or fracture due to weaker muscles, lower bone mineral content, stiffer ligaments and joints.

Seat belts effectively reduce the risk of death and injury [12-13], and effectively protect occupants, and for a wide range of individual characteristics, from older children to older adults [14-15]. Older passengers are more often killed or seriously injured compared to younger passengers in frontal crashes [16]. Older adult occupants are three times as likely as younger to be seriously injured in similar crashes [17].

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People with a wide variety of body size and shape should wear the seat belt properly whenever they are travelling in a car. Shoulder belt fit was judged optimal if the shoulder belt passed over the mid portion of the shoulder [11]. Lap belt fit was judged optimal if the belt was positioned below the anterior-superior iliac spines (ASIS) and in contact with the upper thigh [18]. BMI is the most important factor influencing lap belt fit [19], and is associated with lengthier webbing regardless of seat position or height. Furthermore, Reed et al. [18] showed that occupants with higher BMI positioned the belt higher on the abdomen and farther forward in relation to the pelvis than those with a lower BMI [18-19]. Seat belt fit has been associated with posture, body shape, fat distribution, sex, and BMI [11]. Several studies have shown that a reason for non-usage and misuse of the seat belt is related to discomfort [20-21]. Comfort perception changes with age resulting in more distress due to pressure, chafing, and movement when the seat belt is worn tightly. People sometimes use accessories to reduce discomfort [11], but still feel strapped in and protected in the event of a collision. Perceived safety may be misleading due to a lack of understanding of how a protective system works. There are problems in achieving a comfortable and well-functioning seat belt fit among elderly drivers aged 75 years or older [11].

Only a few studies have been reported so far on seat belt fit and comfort for older adults in cars. Non-optimal belt fit has been associated with parameters such as age, body shape, BMI, sex and anthropometry [22-23]. Bohman et al. [24] showed that the change in body posture due to aging influences belt fit, and that older adults were less aware of safety related to non-optimal belt fit, less explorative when it came to adjusting the seat, and more often brought add-on accessories to improve comfort.

The purpose of this study is to gain further knowledge of seat belt fit, perceived discomfort, and safety awareness among a sample of 55 older adults seated in the front passenger seat of a stationary large passenger car. The study aims to examine how older adults prefer to sit as passengers in cars and what influence of individual measures, such as sex, BMI, height, hip and waist circumferences, have on seat belt fit. In addition, through interviews explore how they perceive their previous experiences of seat belt usage and discomfort related to seat belt fit and safety, and whether they use any accessories to improve comfort.

II. METHODS

This user study was performed at a three-day exhibition for seniors at the Swedish Exhibition & Congress Centre Gothenburg, Sweden in 2018. To attract visitors to part take in the study, an experimental car was placed in an exhibition booth (2x5 meters) together with information about the study on posters and a table with snacks and brochures. Visitors passing by were randomly recruited if they were over 65. The user study involved 55 participants, 32 males and 23 females. Data was lost on shoulder belt information for 3 participants, besides that, data collection was complete for all participants.

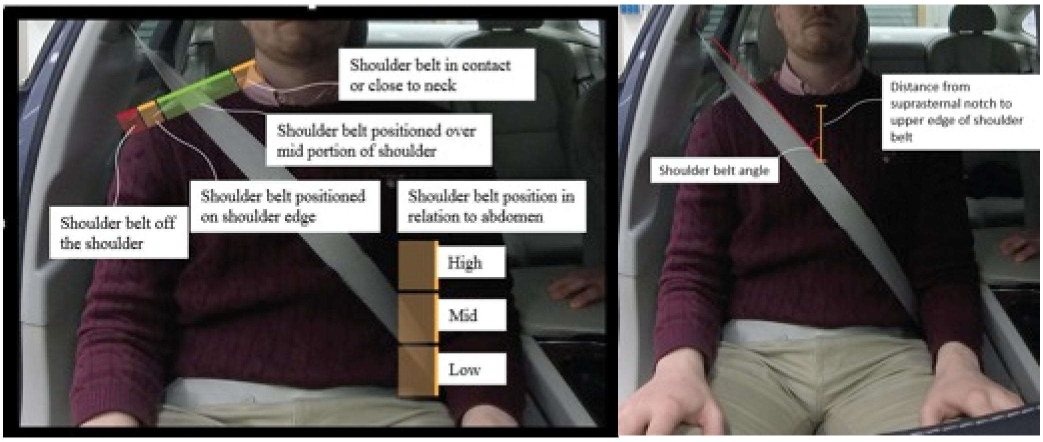
The participants tested the seat/seat belt system in the front passenger seat of a large stationary sedan car. The passenger seat was chosen because in future cars many occupants will be passengers. Two scenarios were tested; (a) a pre-defined seat position (always tested first), and (b) a self-adjusted preferred seat position. A defined seat position was chosen because all participants would sit in the same position and thereby body and sex differences could be tested without considering variations of adjustments made to the seat. However, since Fong et al. [11] and Coxen et al. [22] suggested that using the D-ring adjustment may help to improve seat belt fit, two adjustment levels were used for the shoulder belt height. Either on the second lowest level (pre-defined seat position 1) of the four possible height adjustments, or on the lowest level (pre-defined seat position 2), which was 25 mm lower than pre-defined seat position 1). In both these cases the passenger seat was set at 170 mm from its most forward position, and the back angle was set to 22°. The seat height was set at a low position. The pre-defined seat position corresponds to the seat position for the mid-sized crash test dummy in the EuroNCAP ODB test. In the self-adjusted scenario, the participants were asked to adjust the seat to their preferred seat position. The seat could be adjusted electrically forward/backwards (referred to as seat position, meaning x-position of seat on seat rails), up and down, tilt angle of the seat cushion, and lumbar support.

Test procedure and data collection

Each test session took about 20 minutes and the seat belt was worn for about 5 minutes in each seating scenario, which meant that only initial comfort was tested. Two test leaders ran the tests, one instructing the participant, the other took notes and made measurements. First the participant gave their consent to partake in the study, and then anthropometric measurements of height, weight, waist, and hip circumferences were taken in standing. Also, a side view photo was taken in standing. Next, the participant entered the car and buckled up into the pre-defined position as if going for a real drive. Two photos of seat/seat belt positions including a side and frontal view were taken. One additional photo was taken from the side with the participant's arm raised, for an improved view of the lap belt fit. The cameras used were two GoPRO. One camera was attached to the front window inside the vehicle for a front view picture, and one was attached to a tripod outside the vehicle for a side view picture, with the passenger door open. Next, the participant was asked to unbuckle and adjust the seat in their self-adjusted position, and buckle up again. The instruction was: Adjust the seat to your own preference as if you were going for a trip. Photographs and measurements were taken of the chosen seat position to also quantify seat back angle, height and seat rail position. Finally, structured interviews (questions shown in Appendix) regarding comfort of the two tested seating scenarios were performed after the second test scenario when the participants still were seated in the passenger seat. Questions about habits and previous experiences of seat belt discomfort were asked, and if accessories were used for comfort purposes. If discomfort was perceived it was graded on a scale from 1 (minor) to 10 (major). Also the participants were asked: Without changing the position of the seat belt, how do you evaluate the seat belt position from a safety point of view? If they showed non-optimal belt fit without pointing it out, they were categorized as non-aware. If they had non-optimal belt fit and pointed that out they were categorized as aware. If a participant had positioned the seat belt in a non-optimal position, they were later informed of how the belt should be fitted to achieve good protection.

Data analysis and photographs

From the photographs the shoulder belt position on shoulder (Figure 1a) was categorized into four categories: (i) positioned off the shoulder, (ii) positioned on the shoulder edge, (iii) positioned over mid portion of the shoulder, and (iv) shoulder belt in contact or close to the neck. The lower part of the shoulder belt (Figure 1a) was categorized into three positions: low, mid and high position in relation to the abdomen. The shoulder belt angle was measured from the front (Figure 1b). The distance from the suprasternal notch to the upper edge of the shoulder belt, along the vertical line, was also measured (Figure 1b).



(a) (b)

Fig 1. (a) Four categories of shoulder belt position on shoulder, and three positions of the lower part of shoulder belt on abdomen. (b) Shoulder belt angle, and distance between the suprasternal notch to the upper edge of the shoulder belt.

From the lateral photograph (Figure 2a), the shoulder belt contact with the clavicle was quantified as contact or non-contact with the clavicle, respectively. The lap belt angle was measured from the vertical line to the lap belt line, drawn along the center of the lap belt from the anchorage point up along the pelvis (Figure 2b). Twisted shoulder or lap belt was also notated. The belt position was defined as non-optimal if (i) the shoulder belt position on the shoulder deviated from the mid-shoulder position, (ii) the shoulder belt was not in contact with clavicle, (iii) the lap belt had no contact with the thighs, or (iv) the lap or shoulder belt was twisted. If a participant had at least one non-optimal belt position, the belt fit was categorized as non-optimal. This analysis was made from the photos and the results were also compared with the participants' awareness of whether their belt fit was optimal or non-optimal. From the lateral picture with the participant standing up, the craniovertebral angle (CVA) was calculated (Figure 2c). The CVA is the angle between the horizontal line passing through C7 and a line extending from the tragus of the ear to C7. Queck et al. [7] have shown that there is a correlation between CVA and thoracic kyphosis. In their study they measured CVA in standing posture. BMI was calculated using the equation BMI=weight/(stature*stature).

(a) (b) (c)

Fig 2. (a) Shoulder belt contact with the clavicle was assessed from the lateral view, (b) Lap belt angle measured from vertical line to the centerline of the lap belt, drawn from the anchorage point along the lap belt, (c) The CVA, measured from horizontal line, and the line between the ear and C7.

Descriptive and correlational analysis was used to display the sample. Logistic regression and hierarchical regression was conducted to examine the relationship for nominal and continuous variables respectively.

III. RESULTS

Car travel frequency among the 55 participants was very high, 54 travelled by car weekly and 17 daily. As much as 75% (41) of the participants usually travelled as drivers, 14% equally as drivers or passengers and 11% (6) normally travelled as passengers. In the participant group 32 males and 23 females were included, with an age range of 65-80 years. The average height and weight was 181cm/83kg for males and 167cm/71kg for females. The average BMI was 25 for males and 26 for females. The average CVA was 51°. The CVA was found on average lower among the male participants (49°) compared to the female (54°), which indicates a more forward head posture for the males (Table 1).

TABLE 1 AGE AND ANTHROPOMETRIC DATA OF THE PARTICIPANTS, DIVIDED INTO FIVE GROUPS: ALL, PRE-DEFINED SEAT POSITION 1, PRE-DEFINED SEAT POSITION 2, ALL FEMALES, AND ALL MALES

		Gender (females)	Age (years)		Height (cm)		Weight (kg)		BMI (kg/m^2)		Waist (cm)		Hip (cm)		CVA (°)	
	#	#	Mean	Std dev	Mean	Std dev	Mean	Std dev	Mean	Std dev	Mean	Std dev	Mean	Std dev	Mean	Std dev
All	55	23	72	5	175	10	78	13	25	4	101	11	107	8	51	6
Pre-defined pos. 1	32	12	72	4	176	10	77	11	25	3	100	9	106	6	52	5
Pre-defined pos. 2	23	11	73	5	174	10	80	15	26	5	104	14	110	9	50	7
Females	23	23	72	72	167	8	71	11	26	4	97	11	108	9	54	6
Males	32	-	72	71	181	7	83	12	25	3	104	10	107	7	49	5

Preferred seat position

Participants' preferred seat positions were investigated in relation to anthropometric measurements and in order to examine the relevance of the pre-defined seat position's relevance for passengers when they could choose their seat positions themselves. Table 2 displays the spread in adjustments of the seat positions in terms of seat back angle, seat position, seat length, seat cushion tilt and seat height. The seat back angle and the seat position, was the most frequently seat adjustments.

TABLE 2 DESCRIPTIVE STATISTICS FOR SEAT POSITION AND BACKREST ANGLE, AND THE FREQUENCY OF PARTICIPANTS THAT ADJUSTED SEAT HEIGHT, SEAT CUSHION TILT AND SEAT LENGTH

	N	mean	std dev	minimum	maximum	Seat height increased		Seat cushion tilted upwards		Seat lenght adjusted	
Seat back angle (°)	55	22,5	3,9	10	38	yes	no	yes	no	yes	no
Seat position (cm)	55	11,7	3,2	1	17	22	33	10	45	6	49

No correlations were found between backrest angle and the different anthropometric measures. For seat position, only stature were significantly correlated, r = 0.54, $p<0.05$. Finally, there were significant correlations of 0.37, 0.45, 0.41 and 0.31 ($p<0.05$) between seat height adjustment and stature, weight, waist, and hip measures respectively. For the preferred seat position 56% (31) of the participants adjusted the seat back angle to 22-24°, which was close to the backrest angle in the defined seat positions (22°). A more upright backrest angle (15-22°) was chosen by 17% (9) and a more reclined backrest angle (25-31°) was chosen by 27% (15). Regarding the chosen horizontal seat position 51% (28) adjusted the seat in the horizontal plane, 15 adjusted the seat forwards and 12 backwards. Six participants adjusted the seat more than 5cm forwards or 7cm backwards. The seat height was increased by 40% of the participants, who were average in height or shorter than average. Furthermore, 11% adjusted the seat length and 18% tilted the seat cushion upwards.

Belt fit

Belt fit was classified as optimal or non-optimal. The effect from belt position measures (shoulder belt angle and distance from the suprasternal notch, and lap belt angle) on belt fit was studied, and belt position measures were correlated to anthropometric measures and sex (Figure 3). Thirty-two participants tested the pre-defined seat position 1, and 23 participants the pre-defined seat position 2. No significant differences in shoulder belt fit were found when comparing position 1 and 2. Hence, the two pre-defined seat positions are now on analyzed together.

Overall frequencies of belt fit regarding shoulder position, chest to shoulder contact, lap belt contact with the upper thigh and twisted lap- and shoulder belt are presented in Fig. along with descriptive statistics for belt position variables. Several participants showed more than one issue.

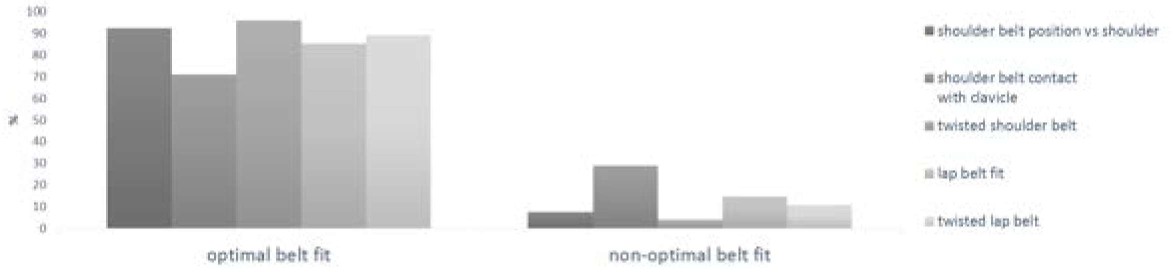


Fig. 3 The distribution of the belt fit measures divided into optimal and non-optimal belt fit.

The majority, 92%, of participants showed an optimal belt fit in terms of shoulder belt position on the shoulder and 71% had shoulder belt contact from chest to clavicle. However, 4% twisted the shoulder belt. Concerning lap belt fit, 85% of participants had optimal belt fit with lap belt contact with the upper thigh, and 11% twisted the lap belt. Of the 26 participants who demonstrated non-optimal belt fit, 21 (80%) assessed their belt fit as correct and safe. Only 3 participants demonstrated safety awareness and recognized the non-optimal belt fit, while 2 were unsure. There were also 3 participants who thought they had a non-optimal belt fit, but the test leader noticed no non-optimal belt position.

The effects of the belt position measures were investigated by applying single and multiple logistic regression analysis. Descriptive statistics are displayed in Table 3. Shoulder belt position on shoulder was in most cases classified as optimal belt fit (mid shoulder position). Only in two cases, the belt was positioned on the edge of the shoulder and close to neck. Mean values indicate that shoulder belt distance should be a good predictor for belt fit, by showing a difference in distance between optimal and non-optimal belt fit for the three belt fit classifications, while the other belt position measures are in the same range no matter if the belt fit classification was optimal nor non-optimal. However, to choose the best regression model, all possible combinations of the variables were tested.

Shoulder belt contact from chest to clavicle was significantly predicted by shoulder belt distance to suprasternal notch, and shoulder belt angle further improved the model according to Akaike's information criterion. The shoulder belt contact increased with creased shoulder belt distance to suprasternal notch and increased shoulder belt angle. Both explanatory variables were significant according to the Wald chi-square test (two-tailed alpha = 0.05). Some details of the results of the simple and multiple logistic regressions are shown in Table 4. No significant model was found for shoulder belt position on shoulder.

Belt fit classifications for males and females are displayed in Table 5. Optimal belt fit with respect to lap belt contact with thigh and shoulder belt contact with clavicle was significantly larger for males than for females. Of the men, 97% had lap belt contact with the thighs, while the corresponding number for women was 70%. Furthermore, 87% of the males showed shoulder belt contact with the clavicle, while 50% of the women showed this optimal belt fit. There was a non-significant trend of more frequent low position of the shoulder belt on abdomen for men; 20% compared to women 14%. No sex difference was found for shoulder belt position on shoulder.

TABLE 3 DESCRIPTIVE STATISTICS FOR THE TOTAL SAMPLE, BELT FIT AND BELT POSITION MEASURES

Belt fit classification		Belt position measure	N	mean	std dev	minimum	maximum
Shoulder belt position vs shoulder	optimal belt fit	shoulder belt angle	48	43	3,6	33	53
		shoulder belt distance fr	48	60	17,6	30	100
		lap belt angle	48	29	3,0	24	36
	non-optimal	shoulder belt angle	4	42	5,3	39	50
		shoulder belt distance fr	4	45	72,9	-39	106
		lap belt angle	4	31	3,4	28	36
Shoulder belt contact with clavicle	optimal belt fit	shoulder belt angle	37	43	3,2	38	53
		shoulder belt distance fr	37	64	20,0	30	106
		lap belt angle	37	30	3,0	24	36
	non-optimal	shoulder belt angle	15	42	4,5	33	50
		shoulder belt distance fr	15	47	31,4	-39	100
		lap belt angle	15	30	3,0	25	36
Lap belt fit	optimal belt fit	shoulder belt angle	45	43	3,9	33	53
		shoulder belt distance fr	45	60	26,1	-39	106
		lap belt angle	47	29	3,5	18	36
	non-optimal	shoulder belt angle	7	42	1,5	39	44
		shoulder belt distance fr	7	52	13,3	37	67
		lap belt angle	8	28	1,9	26	32

TABLE 4 LOGISTIC REGRESSION RESULTS: EFFECTS OF BELT POSITION MEASURES ON SHOULDER BELT CONTACT FROM CHEST TO CLAVICLE

	Estimate	Std error	Wald chisq	p-value
intercept	-0,85			
shoulder belt distance from the suprasternal notch	0,03	0,02	4,11	0,0427
intercept	-11,85			
shoulder belt distance from the suprasternal notch	0,05	0,02	6,56	0,0105
shoulder belt angle	0,24	0,12	4,01	0,0452

TABLE 5 DESCRIPTIVE STATISTICS FOR THE TOTAL SAMPLE, BELT FIT AND SEX

Belt fit classification	N		gender	%	p-value, Fischer's exact test
Shoulder belt position vs shoulder	52	optimal belt fit	female	90,9	1
			male	93,3	
Shoulder belt contact with clavicle	52	optimal belt fit	female	50,0	0,006
			male	86,7	
Shoulder belt position on abdomen	52	low	female	13,64	0,717
			male	20	
Lap belt fit	55	optimal belt fit	female	69,6	0,007
			male	96,9	

For each belt position measures, the correlation to the individual anthropometric measures was investigated (Table 6). For shoulder belt angle, large correlations were found with BMI, weight, waist, and hip circumference. For shoulder belt distance to suprasternal notch a medium strong correlation was found with BMI and stature. Lap belt angle showed a medium strong correlation to BMI.

TABLE 6 BELT POSITION MEASURES CORRELATIONS TO ANTHROPOMETRIC MEASURES, PEARSON CORRELATION COEFFICIENTS, *P<0.05

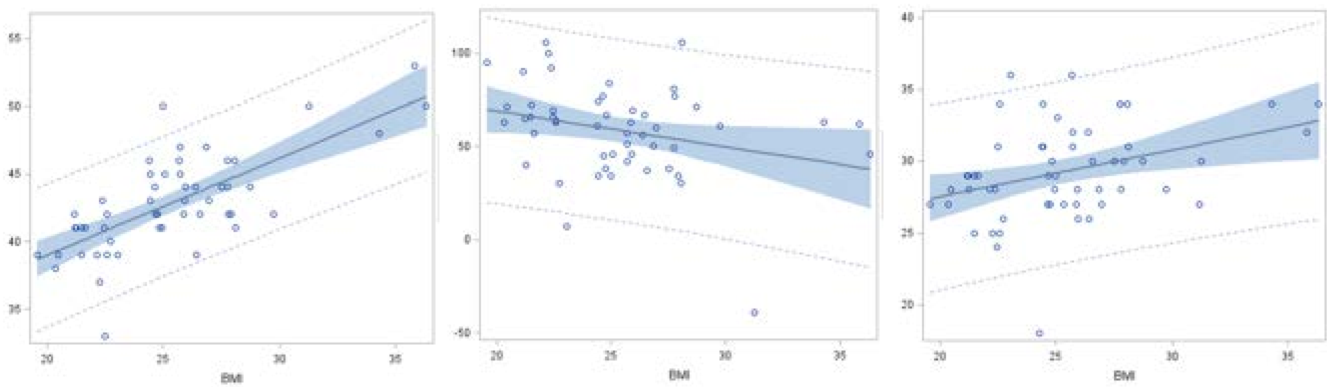
	BMI	CVA	Stature	Weight	Waist	Hip
Shoulder belt angle	0.72*	-0.11	0.17	0.72*	0.70*	0.65*
Shoulder belt distance from suprasternal notch	-0.28*	0.07	0.42*	0.06	-0.02	-0.01
Lap belt angle	0.35*	-0.03	-0.23	0.16	0.32*	0.18

Since BMI showed statistical significant correlations to all three belt position measures, it was further investigated. Single and multiple linear regressions were then used to derive analytical expressions for the belt position measures as a function of BMI (Table 7). For shoulder belt angle, waist significantly contributed in model 2, but did not in model 3. The effect from the sex subsets was also investigated. Table 7 shows details of models with overall significance, with both significant and non-significant hypothesized explanatory variables.

TABLE 7 REGRESSION RESULTS: BELT POSITION AND ANTHROPOMETRIC MEASURES, STANDARDIZED BETA COEFFICIENTS, *P<0.05

		model 1		model 2	model 3
shoulder belt angle	BMI	0.72*		0.47*	0.45*
	waist circumference			0.36*	0.42*
	cv				0.13
	Adjusted R-Sq	0.51		0.57	0.57
shoulder belt distance from the suprasternal notch	BMI, all	-0.28*			
	BMI, women		-0.43*		
	Adjusted R-Sq	0.06	0.14		
lap belt angle	BMI	0.35*		0.17	
	BMI, men		0.42		
	waist circumference			0.13	
	Adjusted R-Sq	0.11	0.18	0.13	

The effect from BMI was significant on all three belt fit measures, showing that increased BMI resulted in increased shoulder belt angle, decreased shoulder belt distance to the suprasternal notch, and increased lap belt angle (Figure 4). When adding waist circumference (model 2) to the model predicting shoulder belt angle, 57% of the variance was explained, compared to 51% with BMI only. According to the standardized beta values, BMI is the strongest predictor of the included anthropometric measures. CVA did not contribute to the model. For the female subgroup, BMI explained 14% of the variability of shoulder belt distance, while BMI did not contribute to the models for men. In opposite, for males, 18% of the lap belt angle was explained, while for the females no effect from BMI was found. Waist circumference did not contribute to lap belt angle explanation.



(a) (b) (c)

Fig. 4 Belt fit measures as a function over BMI, (a) Shoulder belt angle 0,71*BMI + 24,6. (b) Shoulder belt distance = -1,91*BMI + 107,1. (c) Lap belt angle = 0,32*BMI + 21,1. Blue shaded areas represents 95% confidence limits and dotted lines 95% prediction limits.

Perceived discomfort at preferred seat position

In the participants self-adjusted seat position 80% (44) experienced no discomfort while 20% (6 females and 5 males) perceived discomfort at one (8 participants) or several body areas (3 participants). The discomfort was perceived in the lower back, back thigh, bottom, and neck/head. The seat cushion, backrest and headrest were mentioned as causing the discomfort. The intensity of the discomfort graded on a scale from 1-10 showed an average of 4, where 8 was the highest value, and 2 the lowest. None of the participants mentioned the seat belt as a cause for discomfort. One participant perceived the seat cushion as too stiff and discomfort was caused by the edges between the different parts of the cushion. Three participants wanted improved support to the lumbar spine. Two participants perceived the headrest as too high since they could only rest the back of the head on it with no neck support.

Previous experience of discomfort and accessory use

Regarding previously observed discomfort when travelling as passengers in cars 62% (34) did not recall any discomfort. However, 38% (11 males and 10 females) stated that they had noticed discomfort in various body parts; the lower back (8), posterior thigh and buttocks (7), legs and knees (4), and neck (2), rather equally for males and females. All perceived discomfort was associated with the car seat; lack of lumbar support, a stiff and sharp-edged seat base, height of the headrest. When specifically asked if they had perceived discomfort caused by the seat belt, 67% (37) said no, while 33% (18) said yes. Among these, 14 were females and 4 males. The most highlighted problem was discomfort due to the belt in contact with the neck (11 females, 2 males). Other discomfort problems were seat belt pressure (3 females), the seat belt generally uncomfortable to wear (1 male), and the seat belt difficult to reach for height adjustment (1 male).

Nine participants (16%) used add-on accessories in their own cars to improve comfort. Four used an extra cushion to sit on to make the seat softer or improve sitting height for a better field of vision. Two used a pillow for improved neck support, two used a pillow to improve lumbar support, and one used a pillow as an armrest by the door.

IV. Discussion

This explorative user study sought to investigate whether sex, body composition, and posture among elderly front seat passengers in cars may have any effects on seat belt fit and perceived discomfort. The overall results showed that a wide range of belt fit differences was seen due to increased BMI for the older adults. The results also showed a limited safety awareness of sub-optimal belt fit. Furthermore, perceived discomfort from the seat/seat belt system was found to be a problem for some of the participants.

Overall, the shoulder belt was in the mid shoulder position for the majority of participants. The exception from this position was due mainly to the shoulder belt towards the neck. For one of the women with the shoulder belt in contact with the neck (Figure 4b), the belt was positioned in such a way that the breast guided the belt towards the neck. Two other women adjusted their seat to their preferred position by moving it forwards, resulting in the shoulder belt coming in contact with the neck. Adjustment of sitting height or the belt outlet could have improved their belt fit. A tall man with the shoulder belt on the shoulder edge could have improved his belt fit by adjusting the belt outlet to a higher position. This implies possibilities of adjusting a non-optimal shoulder belt position, if people are aware of the non-optimal belt fit and the effects of adjustments on belt fit.

The average BMI for males and females in this study were 25 and 26 respectively, which might be low values when comparing to high-income countries where the elderly cohort soon includes a large number of people with BMI>30. However, when comparing these figures with Statistics Sweden (SCB, 2010) for people between 70-79 years, BMI is equal for women and slightly lower for males.

The participants with a higher BMI (>25) showed a high position of the shoulder belt on the abdomen. Also some participants with BMI around 23-25 had a mid or high shoulder belt position on the abdomen. This can be explained by changes in body constitution due to aging, such as a larger waist circumference, contributing to a higher position of the shoulder belt instead of lying flat over the torso. The results also showed a trend that males were more likely to have the shoulder belt higher up on the abdomen compared to females. Body composition differs between sex [25], and it may be contributing to the difference in lap belt position. BMI does not always capture changes in body composition, such as a larger abdomen (Fig). To capture the shoulder belt position over the lower torso, it may correlate better to waist circumference when measured in sitting, instead, as was done in this study, in standing.

Male - BMI 22.4 Male - BMI 25.7 Female - BMI 21.6 Female - BMI 26.4

Fig. 5 Four participants with different BMI, showing different shoulder belt position on abdomen

Distance between the suprasternal notch and shoulder belt was affected by BMI and further correlated to stature. From a comfort perspective, decreased distance between the shoulder belt and suprasternal notch results in the shoulder belt being closer to the throat, which may result in increased discomfort. However, in this study, few participants experienced shoulder belt contact with the neck, despite decreased distance between the suprasternal notch and shoulder belt. The consequences of such a belt fit in case of a crash needs further investigation. A shoulder belt closer to the throat may reduce torso pitch in a frontal crash. Kent et al. [26] conducted PMHS (Post Mortem Human Subjects) tests with normal weight and obese participants, respectively. It was found that obese PMHS showed less torso pitch due to a delayed restraint effect on the pelvic bones because of adipose tissue. Kent et al. [26] concluded that limited pitch might increase the risk of rib trauma due to shoulder belt loading being greater at the lower torso rather than the upper, including upper ribs and clavicle. However, the contribution of the limited torso pitch due to differences in belt fit seen in the obese and non-obese PMHS, also found in the present study, was not discussed in that study.

Thoracic kyphosis is associated with a forward head posture assessed via the craniovertebral angle (CVA), which more often is found among older than younger adults [6-7]. In a study by Bohman et al. [24] including 11 older and 11 younger participants, a trend was shown that a decreased craniovertebral angle (CVA), i.e. a more forward head posture, resulted in a shorter distance between the suprasternal notch and shoulder belt and an improved contact between the clavicle and the shoulder belt. This is possibly due to the increased curvature of the thorax pushes the upper torso forward, the closer the shoulder belt got to the neck. However, in the present study, no statically significant correlation was found between CVA and belt fit measures.

In this study, females were more prone to have the lap belt higher up on the abdomen than males. Four out of the six females showing high lap belt fit had a high BMI (>25). The older male participants with high BMI guided the belt below the abdomen towards the thighs, resulting in good initial lap belt fit. The difference in fat distribution between males and females [25], may contribute to the difference in lap belt position. Reed et al. [18] reported increased risk of non-optimal lap belt position associated with increased BMI, in terms of having the belt farther forward on the pelvic bone and higher up on the abdomen compared to non-obese occupants. The lap belt angle increased with increased BMI. Increased lap belt angle is associated with increased risk of submarining [27]. In the study by Bohman et al. [24] it was found that the younger participants had a lower lap belt angle (25 degrees) compared to the older adults (30 degrees).

Twenty-one of the 55 participants had non-optimal belt fit in the pre-defined seat position according to four of the measured parameters associated with non-optimal belt fit from a safety point of view; shoulder belt position on the shoulder, shoulder belt contact with the clavicle, lap belt position on the abdomen, and twisted belt. Even in their preferred position, 26 participants showed non-optimal belt fit. The increased non-optimal belt fit included several participants with no contact between the shoulder belt and clavicle, due to changes in the seat position. Only three participants acknowledged the seat belt fit as good when it was non-optimal, the other participants did not reflect on the seat belt fit, nor adjusted the seat position to improve belt fit. On the contrary, some participants even made the belt fit worse after adjusting the seat to their preferred position, mainly related to shoulder belt contact with clavicle. Twisted belt is considered as of minor importance compared to lap belt high on abdomen and shoulder belt on shoulder edge, with the rationale that a seat belt pre-tensioner may reduce the slack accompanied with twisted belt. In relation to getting the highest injury prevention effect of the safety belt, the seven participants who in their preferred position showed lap belt on abdomen and shoulder belt on edge of the shoulder may be of more concern in case of a crash compared to the other types of non-optimal belt fits. This since the lap belt may not engage the stronger pelvis bone optimally.

Several participants made adjustments to their preferred seat position to gain a higher seat position motivated by a better overview in addition to adjusting the front/rearward position of the seat. Only one changed the shoulder belt outlet position. The differences in seat position between the pre-determined seat position (corresponding to the standardized crash test method) and their preferred seat position, indicate the importance of evaluating restraint systems in a variety of seat positions to ensure a robust performance in real world situations. In addition, the participants gave an impression of not wanting to push buttons and explore the results due to seat electricity adjustments' complexity. This assumption was however only based on the subjective impressions from the test leaders, and not quantified. In the study by Bohman et al. [24], it was also found that the older adults were less explorative of the seat position functions of the study vehicle than the younger participants. Older adults should be encouraged to explore and understand the possibilities of adjustments the car seat offers.

In the present study, 16% of the older adults said they brought an accessory when going for a ride, including pillows to improve sitting height and support the lumbar spine or neck. In a previous study by Brown et al. [23] 21% of 380 older adult participants brought an accessory to improve the comfort of the seat belt (9%) and/or to the seat (17%). In the study by Bohman et al. [24] it was also shown that some older adults used cushions to improve sight and comfort of the back. Since some older adults have a more kyphotic spine and thus a more forward flexed sitting posture they may require a more pronounced lumbar support and also a higher seat cushion to sit higher up for improved field of vision. However, some older adults' discomfort issues related to the use of accessories may actually be solved by functions offered in modern car seats, including lumbar spine supports and height adjustments of the seat.

This study was limited to static testing; no driving was included and only the passenger seat in a large sized car was used. However, in future cars occupants may more often be regarded as passengers, and therefor the seat belt fit was studied only for this position. Due to each scenario being limited to 10 minutes of wearing the seat belt, only initial comfort was studied. Since discomfort increases with time [28] the initial discomfort found among the participants may have increased. Qualitative estimation of shoulder and lap belt fit was made through analyses of photos using three analysts to improve internal reliability. However improved lap belt fit assessment could be achieved if palpating the ASIS points of the participants' pelvises and measure the distance between the ASIS and the lap belt fit, as has been described by Reed et al. [18].

The seat belt is part of the total restraint system in the car, which also includes the seat and the vehicle compartment. The compartment contributes with support areas such as armrest, floor, knee support, door panels and also other systems that may deploy during a crash. The goal when designing the restraint system of a car should be to achieve a proper belt fit without having to educate the user in how the belt should be adjusted and worn; the design should intuitively offer proper belt fit and comfort. The results regarding body constitution and posture for elderly can also be used to improve the design of other sitting devices such as seats in trucks or other types of vehicle for public transportation, office chairs and furniture for society and home where elderly spend their time.

V. CONCLUSIONS

There was a wide range of seat belt positions found among the participants in this study, and part of this range was considered as non-optimal in relation to possible maximum protection of the seat belt. The participants had limited safety awareness of their non-optimal shoulder and lap belt fit.

The majority of the participants had the shoulder belt on a mid shoulder position. However, individual differences are apparent. Participants with higher BMI and waist circumferences positioned the lower part of the shoulder belt high up on the abdomen, resulting in the shoulder belt closer to the neck and a shorter distance to the suprasternal notch, compared to occupants with a lower BMI. The consequences of this shoulder belt position on abdomen need to be explored in crash tests for further understanding. BMI and abdominal shape also influenced the lap belt position, with men more likely to route the lap belt below the belly and in contact with the thighs.

The majority of the participants perceived no discomfort in this static user study. However, some participants reported that they perceived discomfort due to the seat and/or the seat belt in their regular driving, and several participants brought accessories to improve comfort.

This study contributes with detailed information on belt fit and influencing factors providing valuable input into protection systems addressing safety for all ages of occupants.

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VIII. Appendix

Structured interview questions, which were asked after the test when the participant still was seated in the self-adjusted seat position:

1. How do you usually travel by car?
2. How many times a week do you travel by car?
3. Do you feel discomfort somewhere on the body as you are sitting now? If you feel discomfort in several body regions respond to where you feel most discomfort.
4. State on a scale from 1 to 10 how much discomfort you feel in this body region.
5. What in the car is the main reason for this perceived discomfort?
6. Do you feel discomfort somewhere else on the body worth mentioning?
7. State on a scale from 1 to 10 how much discomfort you feel in this/these body region/s.
8. What in the car is the main reason for the perceived discomfort?
9. Without changing the position of the seat belt, how do you evaluate the seat belt position from a safety point of view?
10. What settings do you usually use when adjusting the chair?
11. What is the reason why you make these settings?
12. Do you use or have you used any accessories when traveling by car?
13. What is the main reason for this?