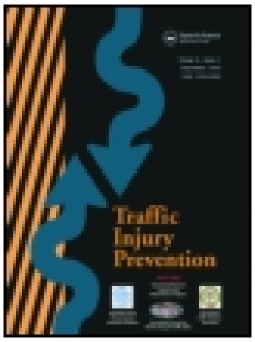

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A comparison of seat belt fit and comfort experience between older adults and younger front seat passengers in cars

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ABSTRACT

Objective: The purpose was to study how occupant age affects seat belt fit and comfort by comparing older adults and younger occupants in the front seat of a passenger vehicle.
Methods: An exploratory user study was performed for the front seat of a stationary large passenger vehicle in a laboratory environment, including 11 older (aged 72–81) and 11 younger (aged 25–30) participants. Each participant first entered the vehicle and buckled up in a predefined seat position. Next, they adjusted the seat to their preferred seat position and buckled up again. Anthropometric data were collected on height, weight, and waist and hip circumferences. Photographs and measurements were taken of seat/seat belt positions and posture, and structured interviews were conducted regarding comfort perceptions of the 2 tested scenarios, including previous experience and awareness of seat belt usage and discomfort experienced as passengers in cars.
Results: Nonoptimal belt fit included shoulder belt on the shoulder edge or close to the neck or lap belt over the abdomen. Five of 11 older adults had nonoptimal belt fit in the predefined position, and in the preferred position 7 older adults had nonoptimal belt fit. Only one showed safety awareness and recognized the nonoptimal belt fit in the preferred position. In the younger group, 4 of 11 had nonoptimal belt fit in the predefined position and 4 in the preferred position. Two acknowledged the nonoptimal belt fit. Older adult participants with a more pronounced kyphotic posture had the upper part of the shoulder belt positioned closer to the suprasternal notch compared to younger participants. Older adults were also more likely to have the lower part of the shoulder belt higher up on the abdomen compared to younger participants. Participants with higher body mass indexes (BMIs) were more likely to have the shoulder belt higher up on the abdomen, independent of age and gender. When the shoulder belt was positioned higher up on the abdomen the upper portion of the shoulder belt was routed closer to the throat. Older adults preferred to sit higher up to achieve a better field of vision compared to younger adults.
Conclusions: The change in body posture due to aging influences belt fit. Older adults seemed less aware of safety related to belt fit. Increased BMI influenced shoulder belt fit, independent of age. These findings are important when designing restraint systems to ensure safety for all occupants.

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Older adults; belt fit; user study; lap belt; shoulder belt; passenger safety

Introduction

Today, people live longer and the older population is increasing, especially in the Western world. The estimated life expectancy is now 83 years, and in 2030 1 of 4 persons will be over 65 (Roser 2019). Older adults are healthier today and engage in travel, social, and health-promoting activities (Schmöcker et al. 2008; Clarke et al. 2009; Cole et al. 2010; Arai et al. 2011). They travel often in cars and are accustomed to deciding when, where, and how to travel. Mobility, comfort, and safety are important.

Older adults are more fragile than younger adults and thereby have an increased risk of injury due to weaker muscles, lower tolerance for fractures, stiffer ligaments, and degenerated discs. Every third woman and every sixth man near age 70 suffer from osteoporosis, which weakens the skeleton and leads to an increased risk for fractures. About 50% of the population over 70 suffers from arthritis, and 20–40% have kyphosis, an excessive convex spine curvature (Peacock and Karwowski 1993).

With age, redistribution of fat occurs, resulting in more fat, less muscle mass, and an increased body mass index (BMI). However there are age-related changes in the distribution of body fat that are not adequately captured by an increased BMI (Fong et al. 2016). Body height decreases, and a more forward-leaning posture arises. All of these changes lead to an overall body shape change, resulting in altered posture, in both sitting and standing (Wells et al. 2007).

Seat belts are an important safety feature in vehicles, contributing to saving lives and reducing the risk of injury (Kahane 2000). Older adult occupants are 3 times as likely as younger occupants to be seriously injured in similar

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crashes (Welsh et al. 2006). The seat belt should fit a wide variety of body sizes. For older adults, changes in posture and fat distribution can lead to difficulties with belt fit. In a study by Fong et al. (2016), the shoulder belt fit was judged optimal if the shoulder belt passed over the mid-portion of the shoulder. Lap belt fit was judged optimal if the belt was positioned below the anterior–superior iliac spines (ASIS) landmarks and in contact with the upper thigh (Reed et al. 2013). Reed et al. (2012) stated that BMI is the most important factor influencing lap belt fit and is associated with lengthier webbing regardless of seat position or height. Reed et al. (2013) 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.

Comfort changes with age. Several studies have shown that a reason for nonusage of the seat belt is related to discomfort (Fockler and Cooper 1990; Begg and Langley 2000). Older adults are more sensitive to pressure, chafing, and movement. This may result in the seat belt being perceived as uncomfortable when worn tightly, and efforts to minimize discomfort may lead to incorrect usage. People sometimes use accessories such as pillows to reduce discomfort (Brown et al. 2016; Fong et al. 2016) but still feel strapped in and protected in the event of a collision. Perceived safety is misleading due to a lack of understanding of how a protective system works.

Only a few studies have been reported on how occupants' aging affects belt fit in cars. Nonoptimal belt fit has been associated with a number of parameters, such as age, body shape, BMI, gender, and anthropometry (Coxon et al. 2014; Fong et al. 2016). In these studies, occupant perception regarding belt fit has not been included, which might provide further understanding of discomfort and repositioning behavior. To gain greater knowledge of this field, the purpose of this study was to examine how occupant age influences belt fit and perceived comfort by comparing older adults and younger occupants in the front seat of a passenger car.

Methods

This laboratory study was conducted with 11 older adult participants (72–81 years of age, 7 men, 5 women) and 11 younger occupants (25–30, 7 men, 5 women). The older adult participants were selected from a retirement organization, and the younger participants were students. All people participated voluntarily.

The participants were positioned in the front passenger seat of a large stationary sedan. Two scenarios were tested: One predefined seat position (always tested first) and one self-adjusted seat position.

In the predefined scenario, 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. These settings are in accordance with European New Car Assessment Programme seating protocol used in frontal crashes for a midsized male crash dummy (European New Car Assessment Programme 2018). The shoulder belt was adjusted to the second lowest level of the 4 possible height adjustments. In the self-adjusted scenario, participants were asked to adjust the seat to their preferred seating position (Tables A1 and A2, see online supplement).

Test procedure and data collection

Two test leaders ran each test, one instructing the participant and the other taking notes and measurements. First, the participant gave consent to partake in the study. Anthropometric measurements were taken such as height, weight, and waist and hip circumferences, and a side view photo was taken in standing. Next, the participant entered the car and buckled up into the predefined position as if going for a real drive. Two photos of seat/seat belt positions including side and frontal views 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 2 GoPro cameras (Hero 6) attached to the front window and to a tripod outside the vehicle. Next, the participant was asked to unbuckle and adjust the seat in his or her self-selected position and buckle up again. The instruction was as follows: 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 quantify seat back angle, height, and seat rail position. No quantifications were made of seat height or seat cushion tilt; the test leader only visually noticed and noted whether a change was made.

Finally, structured interviews were conducted regarding comfort of the 2 tested scenarios (Table A3, see online supplement). In addition, questions about the participants' previous experiences of seat belt usage and discomfort were asked and whether accessories were used for comfort purposes. 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 had nonoptimal belt fit without pointing it out, they were categorized as nonaware. If they had nonoptimal belt fit and pointed it out they were categorized as aware. The test session took 45 min, and the seat belt was worn for 10 min in each scenario, which meant that only initial comfort was tested. If a participant had positioned the seat belt in a nonoptimal position, he or she was informed about the nonoptimal belt fit and how the belt should be fitted to achieve good protection. As compensation, the participants received 2 cinema tickets.

Data analysis of photographs

From the photographs, the shoulder belt position (Figure 1) was categorized into 4 categories: (1) Shoulder belt in contact or close to the neck, (2) positioned over mid-portion of the shoulder, (3) positioned on the shoulder edge, and (4) positioned off the shoulder. The lower part of the shoulder belt was categorized into 3 positions: Low, mid, and high position in relation to the abdomen. The distance from the suprasternal notch to the upper edge of the shoulder belt, along the vertical line, was also measured.

From the lateral photograph in Figure A1 (see online supplement), the shoulder belt contact with the clavicle was categorized as contact or noncontact, 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 A2, see online supplement). Twisted shoulder or lap belt was also notated.

The parameters analyzed from the photo included shoulder belt position on the shoulder, shoulder belt contact with clavicle, lap belt position on the abdomen, and a twisted belt, of which all could be associated with nonoptimal belt fit. If a participant had at least one nonoptimal belt position, the belt fit was categorized as nonoptimal. Several participants showed more than one issue. These parameters were compared with the participants' awareness of whether their belt fit was optimal or nonoptimal.

From the lateral picture with the participant standing up, the carniovertebral angle (CVA) was calculated. The CVA is the angle between the horizontal line passing through C7 and a line extending from the tragus of the ear (Figure A2). Quek et al. (2013) have shown that there is a correlation between CVA and thoracic kyphosis. In their study, they measured CVA in standing posture.

Results

All participants traveled weekly either as drivers or passengers. For the older adult participants, age ranged from 72 to 81 (average 76) and for the younger between 25 and 32 (average 27). BMI ranged from 17 to 31 among the older adults and from 19 to 42 among the younger. The average CVA was 58° for the younger participants and 51° for the older adults. Among the older adults there was a group of 5 participants who had a more pronounced kyphotic spine, resulting in low CVA angles (average 44°, ranging from 41° to 47°). All anthropometric data can be found in Tables A3 and A4 (see online supplement).

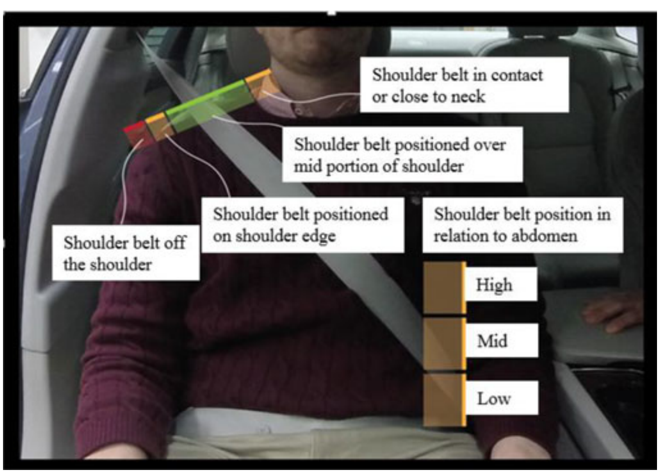

Figure 1. Lateral shoulder belt fit assessment with the shoulder belt positioned off the shoulder, on the shoulder edge, on the mid-portion of the shoulder, or in contact/close to the neck. Lower shoulder belt fit on the abdomen was low, mid, or high position.

Shoulder belt fit

The difference between defined and preferred seat position did not result in a pronounced difference in shoulder belt position on the shoulder or shoulder belt contact with clavicle for either group. In the defined position, the shoulder belt was on the mid-shoulder for 7 older adult participants and for 10 younger participants. Ten of the older adults and 9 of the younger adults had belt contact with the clavicle (Table 1). Six older adult participants had the shoulder belt high on the abdomen in the defined position, and 8 younger participants had the belt positioned low on the abdomen. Examples of different belt fits are shown in Figure 2. The average distance from the suprasternal notch to the upper edge of the shoulder belt was on an average 46 mm for the older adults and 69 mm for the younger adults in the defined seat position (Table A5, see online supplement).

Lap belt fit

In each scenario, only one participant in each group lacked contact with the upper thigh with the lap belt (Figure 3). The lap belt angle was on average higher for the older adults than for the younger participants, for both predefined and preferred positions (Figure 3). A higher BMI led to an increased lap belt angle for both older adults and younger participants.

Overall seat belt fit and safety awareness

The analysis of overall seat belt fit was made on the shoulder belt position on the shoulder, shoulder belt contact with the clavicle, lap belt position on the abdomen, and twisted belt. These parameters can be associated with nonoptimal belt fit.

Four older adults showed a nonoptimal belt fit in the defined seat position. In the preferred seat position, 6 older adults showed nonoptimal belt fit. Three participants had

Table 1. Results of shoulder belt position divided into 4 groups: Older adults and younger in the defined or preferred seat position. Including shoulder belt position on the shoulder, related to 4 positions (close to the neck, mid-shoulder, shoulder edge, off shoulder), shoulder belt contact with clavicle (contact or no contact), the shoulder belt position on the abdomen, related to 3 positions (high, mid, low, average distance, mm) of the vertical line from the suprasternal notch to the shoulder belt.

		Defined position, older adults	Defined position, younger adults	Preferred position, older adults	Preferred position, younger adults
Shoulder belt position on shoulder	Neck	2	1	3	1
	Mid-shoulder	7	10	6	10
	Far out	2	0	2	0
	Off shoulder	0	0	0	0
Shoulder belt contact with clavicle	Contact	10	10	9	9
	No contact	1	1	2	2
Suprasternal notch to seat belt	mm	46	69	45	73
Shoulder belt position on abdomen	High	6	3	7	3
	Mid	2	0	1	0
	Low	3	8	3	8

Figure 2. (Top left) Older participant with shoulder belt on edge of shoulder and low shoulder belt position on the abdomen. (Top right) Older participant with mid-shoulder position and high shoulder belt position on abdomen. (Bottom left) Younger participant with shoulder belt on mid-shoulder and low shoulder belt position on abdomen. (Bottom right) Younger participant with shoulder belt against the neck and high shoulder belt position on the abdomen.

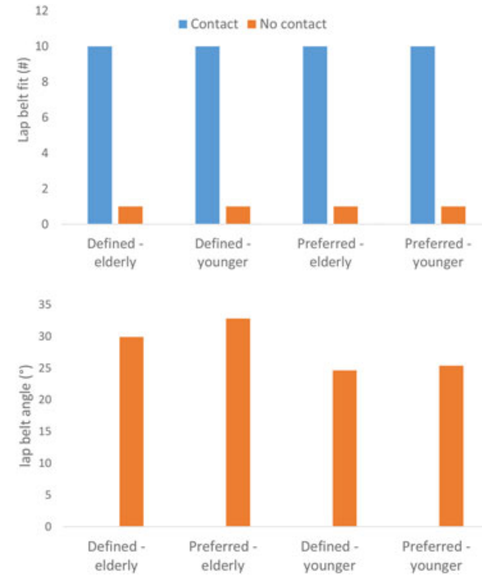

Figure 3. (Left) lap belt fit, in terms of contact with the thigh, for older adults and younger participants in the defined or preferred position. (Right) Average lap belt angle for older adults and younger participants in the defined or preferred position. Divided into 4 groups: Older adults and younger in the defined or preferred seat position. Each participant could have more than one nonoptimal belt fit.

the shoulder belt on the shoulder's edge or nonoptimal lap belt fit for both defined and preferred position (Figure 4). Two demonstrated safety awareness and recognized the nonoptimal belt fit in the preferred position. The other participants showed nonoptimal belt fit due to the shoulder belt close to the neck, twisted belt, or no contact with the clavicle. None of these participants recognized these nonoptimal belt fits.

In the younger group, 4 participants showed nonoptimal belt fit in the predefined position. Four participants had nonoptimal belt fit in the preferred position, including 2 participants with no shoulder belt contact to the clavicle, one participant with shoulder belt contact with the neck, and another participant with the lap belt high on the abdomen. All of these participants recognized their nonoptimal belt fits. Detailed data is shown in Table A5.

Discomfort, accessories, and seat adjustments

Three younger and 3 older adult participants experienced discomfort while seated in their preferred seat position. One source of distress was stated to be related to the seat belt being in contact with the neck, and the other problems experienced were related to the seat causing discomfort to various body regions: Head, neck, bottom, and lower back.

One younger participant usually uses a pillow to support the lower back while riding in a car. Three older adult participants normally brought accessories. One brought a pillow to improve the sitting height and an add-on lumbar support; the others brought a pillow to support the head during longer journeys.

Seven of the younger participants moved the seat (5 forwards, 2 backwards), and 4 of the older adults moved the seat (2 forwards, 2 backwards), to gain their preferred seat position. Six older adult participants and one younger participant raised their seats. The older adults chose a more tilted seat back position compared to the younger participants (Tables A1 and A2).

Discussion

This exploratory user study sought to investigate whether body composition and posture among older adult front seat passengers in cars may have an effect on belt fit and experienced comfort compared to younger adults. The overall results showed a wide range of belt fit differences for all participants, regardless of age, providing both qualitative and quantitative input to seat belt design.

The lateral shoulder belt position on the shoulder differed only slightly between the older and younger participants, and there was no difference in shoulder belt contact with

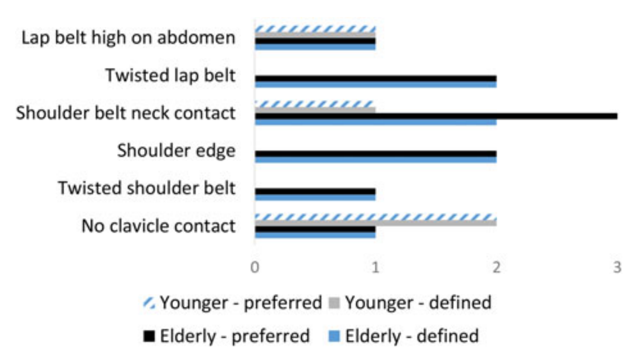

Figure 4. The total number of nonoptimal belt fits sorted by no shoulder contact, twisted shoulder and lap belt, shoulder belt on the shoulder's edge, shoulder belt in contact with the neck, and lap belt positioned high on the abdomen, divided into 4 groups: Older adults and younger in the defined or preferred seat position. Each participant could have more than one nonoptimal belt fit.

the clavicle. The majority showed a mid-shoulder position of the shoulder belt. However, the shoulder belt position on the abdomen was commonly higher for the older adults than for the younger. This resulted in a shorter distance between the suprasternal notch and shoulder belt for the older adults. Participants with higher BMIs (>25) showed a high position of the shoulder belt on the abdomen, for both older and younger adults. Due to the low number of participants, conclusions regarding differences between older and younger adults with high BMIs for shoulder belt fit cannot be drawn. Nevertheless, changes in body constitution due to aging, such as a larger waist circumference, contribute to a higher position of the shoulder belt on the abdomen.

In this study, no trend was found that stature influenced shoulder belt distance to suprasternal notch. Furthermore, no trend was shown that belt fit was influenced by the height of the participants in either group, but this may have to do with the small sample sizes. However, in a study including 55 older adult participants, Osvalder et al. (2019) found that increased height led to increased shoulder belt distance to suprasternal notch and that taller participants were more likely to have shoulder belt contact with the clavicle compared to shorter occupants.

Thoracic kyphosis is associated with a forward head posture assessed via the CVA, which more often is found among older than younger adults (Katzman et al. 2010; Quek et al. 2013). In the present study, a decreased CVA resulted in a shorter distance between the suprasternal notch and the shoulder belt, possibly due to the increased curvature of the thorax pushing the upper torso forward, which pushes the shoulder belt closer to the neck. However, not all older adult participants had a low CVA. Hence, this trend in shoulder belt fit may be common among older adults with a developed kyphosis, and men more commonly develop kyphosis than women (Bartynski et al. 2005). Because both of these parameters push the shoulder belt closer to the suprasternal notch, further studies with a larger number of participants are needed to understand the combined effect of BMI and CVA on shoulder belt fit. From a comfort perspective, decreased distance between the shoulder belt and suprasternal notch results in the shoulder belt getting closer to the throat, which may result in increased discomfort. The consequences of such a belt fit in case of a crash need further investigation. Kent et al. (2010) conducted postmortem human subjects (PMHS) tests with normal-weight and obese participants. It was found that obese PMHS showed less torso pitch due to a delayed restraint effect on the pelvic bones due to adipose tissue. Kent et al. (2010) concluded that limited pitch might increase the risk of rib trauma due to greater shoulder belt loading at the lower torso instead of 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 nonobese PMHS, also found in the present study, was not discussed in that study.

Lap belt fit was determined by 2 factors: Whether the lap belt was in contact with the upper thighs and the lap belt angle. Increased lap belt angle is associated with increased risk of submarining (Håland and Nilsson 1991). The results showed that the lap belt was in contact with the thighs for all participants except one in each test group. A higher lap belt angle was found for the older adult participants compared to the younger, which may be associated with increased waist circumferences. Reed et al. (2013) reported increased risk of nonoptimal 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 nonobese occupants. However, in this study, several of the older adult participants with high BMIs guided the belt below the abdomen toward the thighs, resulting in good initial lap belt fit.

Four of the 11 older adult participants had nonoptimal belt fit according to the measured parameters associated with nonoptimal 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, 6 showed nonoptimal belt fit. From the interviews, it was found that the older adults had less awareness of the importance of belt fit compared to the younger, particularly for belt fit associated with the shoulder belt on the shoulder edge and the lap belt in a high position on the abdomen. Some of the older adults, who in their preferred seat position had nonoptimal belt fit, acknowledged the seat belt fit as good. They did not reflect on the seat belt fit or adjust the seat position to improve belt fit. On the contrary, some even made the belt fit worse after adjusting the seat to their preferred position. One occupant moved the seat forward, resulting in shoulder belt contact with the neck. Another occupant reclined the seat backwards, resulting in contact between the shoulder belt and the clavicle being removed. When the older adult participants were later told how and why they should use the seat belt, some commented, “I remember the time when cars did not even have seat belts.” They had attitudes such as “as long as I wear the seat belt, it’s all good,” compared to the younger participants, who seemed more aware of the importance of placing it correctly. In this study, a twisted belt was considered of minor importance compared to a lap belt high on the abdomen and shoulder belt on the shoulder edge, with the rationale that a seat belt pretensioner may reduce the slack associated with a twisted belt.

In general, the older adults made adjustments to their preferred seat position to gain a higher seat position compared to the younger participants, motivated by a better overview of the traffic situation.

Only one participant complained about discomfort due to shoulder belt chafing at the neck. However, each scenario was limited to 10 min of wearing the seat belt. Therefore, only the initial belt fit and comfort were studied. Because discomfort increases with time (Vink and Lips 2017), the initial discomfort found among the participants may have increased.

In a previous study by Brown et al. (2016), 21% of 380 older adult participants brought an accessory into the vehicle to improve the comfort of the seat belt (9%) and/or the seat (17%). In a study including 55 older adult participants, Osvalder et al. (2019) found that 16% of the older adults brought an accessory when going for a ride, including pillows to improve sitting height and support the lumbar spine or neck. In the current study, only 1 younger participant and 3 older adults would normally bring an accessory.

In the current study, it was possible to adjust the seat electrically forward/backwards, in height, tilt angle of the seat cushion, and lumbar support. The younger participants explored the possibility of changing the seat to a higher degree than the older adults, who gave an impression of not wanting/daring to push buttons and explore the results. This assumption was, however, only based on the subjective impressions from the test leaders and was not quantified. None of the participants changed the shoulder belt outlet position. 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 limitations of this user study regarding belt fit and initial comfort include that it did not include driving and was limited to the passenger seat in a medium sized car. Only 11 older adults and 11 younger participants were included. With this number of participants it is possible to gain an increased understanding of the topic but the result cannot be generalized. To broaden the knowledge on how belt fit can change in a population, studies with a larger number of people with various weights, heights, BMIs, ages, and genders should be conducted. Qualitative estimation of shoulder and lap belt fit was made through analyses of photos using 2 analysts to improve internal reliability. However, improved lap belt fit assessment could be achieved by palpating the ASIS landmarks of the participant's pelvis and measuring the distance between the ASIS landmarks and the lap belt, as described by Reed et al. (2013).

In conclusion, there was a wide range of seat belt positions found among the participants in this study, regardless of age. The older adults showed a trend of nonoptimal lap belt fit. Both younger and older participants with increased BMIs positioned the lower part of the shoulder belt high up on the abdomen, resulting in the shoulder belt closer to the neck, compared to occupants with normal BMIs. The consequences of this need to be explored in crash tests for further understanding. Participants with decreased CVA had the shoulder belt closer to the suprasternal notch, resulting in the shoulder belt being closer to the throat, compared to participants with a higher CVA, regardless of age. The older adults were less aware of safety issues related to belt fit compared to younger participants. This study provides valuable input into designing restraint systems, addressing safety for occupants of all ages.

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