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Elderly passengers in cars

- Study of belt fit and comfort

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Foreword

This master thesis was carried out during the spring of 2018, by two students at Industrial Design Engineering, Chalmers University of Technology. The project was carried out as part of a research project conducted by Volvo Cars. The work was carried out at SAFER- Vehicle and Traffic Safety Centre at Chalmers, Gothenburg, Sweden and funded by FFI-Strategic Vehicle Research and Innovation, by Vinnova, the Swedish Energy Agency, the Swedish Transport Administration and the Swedish vehicle industry.

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Summary

This master thesis was part of a research project which investigate assessment methods for a heterogeneous population of passengers in future vehicles. This master thesis aimed to investigate elderly and how aging affect seat belt fit and comfort for passengers in cars.

Two user studies were conducted to study belt fit and comfort of occupants in the front passenger seat. The first user study was used for comparing old and young participants. The second user study was performed at an exhibition with elderly visitors and aimed at investigating factors within the group of elderly.

A procedure was developed for the user studies which included structured interviews, observations, and documentation of different measurements. The interviews were used to study awareness, experience of discomfort and previous experiences as passengers in cars. The observations included photographs of the seated participants in the front passenger seat and standing outside the car. The photographs of the participants were used to analyze the seat belt fit and the posture of the participants. The measurements were used to document body related data as well as for measuring factors related to the seat and seat belt.

The results of the project show that aging in some aspects affect seat belt fit and comfort. The elderly participants were found to have a different posture which affected the seat belt fit compared to young. Furthermore, a difference was found in attitude, preference, and awareness between old and young. Elderly were found to be less aware of their seat belt fit and less explorative when it comes to adjusting the seat. Elderly were also found to prefer to sit higher to achieve a good field of sight compared to younger. Based on the findings 10 design guidelines were developed.

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Glossary

Add-on accessory – Any type of product not included in the car design which occupants use to improve seat belt and seat comfort.

ASIS – Abbreviation for anterior superior iliac spine and refers to a bony projection of the iliac bone which is an important point to determine if the lap belt is placed good on the lap.

Belt fit – A term used to describe how well a seat belt fit an occupant.

BMI - The body mass index (BMI) is a value derived from the mass (weight) and height of an individual. The BMI is defined as the body mass divided by the square of the body height and is universally expressed in units of kg/m2, resulting from mass in kilograms and height in meters.

BFMI – Body fat mass index.

Old participant – Refers to participants aged 65 years or older.

Chosen seat position – Refers to the position of the passenger seat when the participants have adjusted it as they wanted.

CVA – Abbreviation of the craniovertebral angle which is used to measure the forward head posture of an individual.

D-ring adjustment – The shoulder belt height adjustment (4 levels in Volvo S90, 2017).

Defined seat position – Refers to a predetermined adjusted seat used to compare participants with the same seat adjustments.

FFM – Fat free mass.

FM – Fat mass.

Iliac crest – The upper edge of the pelvic bone.

Kyphosis – Refers to postural kyphosis, a slouched posture and opposite to Lordosis. In common language it refers to a rounded upper back.

Lap belt – Refers to the horizontal part of the 3-point belt placed over the occupant lap.

Shoulder belt – Refers to the diagonal part of the 3- point belt used in regular cars.

Slack – Refers to the distance of the seat belt which would disappear if the seat belt was tightened up around the occupant body.

Suprasternal notch – A visible dip between the neck and the two collarbones.

Overall belt fit – A term used to describe the overall belt fit including both the shoulder belt and lap belt.

Young participant - Refers to participants aged between 25 and 35 years old.

1. Introduction

This chapter provides an introduction to the master thesis. The background, aim, research questions and delimitations of the thesis are presented. Furthermore, the chapter present the outline of the thesis.

1.1 Background

Today's cars occupant protection is based on standardized testing and standardized crash dummies, covering a limited part of the population. Advancements are ongoing developing more advanced tools to evaluate occupant protection, in terms of mathematical models of human beings, so called human body models (HBM). As these tools develops, it opens up the possibilities to assess occupant protection for a greater part of the population.

It has been recognized that a major shift is occurring in the population age distribution in motorized countries, resulting in that a growing number of older persons have increased need for mobility. In the year of 2030 one in four persons will be aged over 65 (Welsh, Morris, Hassan, & Charlton, 2006). With the increasingly aging population and the development of automated cars, a higher percentage of elderly people will most likely be travelling by cars. The older population differs from the younger regarding musculoskeletal characteristics and physical abilities. Body size, range of motion and joint flexibility as well as strength are the major categories affecting the elderly population compared to the younger population (Peacock & Karkowski, 1993). Thus, it is of interest to investigate if any of the factors related to aging affect elderly people's safety and comfort as passengers in cars. There are only a few studies done on how aging affects belt fit for elderly people in cars. This master thesis is part of a larger research project concerning passenger safety in general conducted by Volvo Cars (VCC) and partners are Autoliv and Chalmers University of Technology. This thesis focus on belt fit and comfort aspects for elderly passengers aged 70 years or older. The larger project wants to map any differences between elderly and other passengers and investigate the possibility of having an occupant protection system adapted for elderly people without compromising the comfort and safety for passengers in general.

1.2 Aim

The aim of the thesis is to investigate if and how aging affect elderly people's seat belt fit and comfort experience as passengers in cars, focusing on the intended user group of elderly people above 70 years.

The project will result in a list of design guidelines related to elderly passengers in cars, focusing on safety and comfort. The guidelines are the final delivery of the project and will consist of topics that are recommended to be considered when designing an occupant restraint system and seat for including elderly passengers.

1.3 Research questions

The following research questions are to be investigated:

- How does aging affect seat belt fit and comfort for passengers in cars?
- How does the intended user group experience comfort in today's cars compared to a young reference group?
- How does elderly prefer to sit as passengers and how aware are elderly of safety related to seat belt fit compared to a young reference group?

1.4 Delimitations
Due to the size and scope of the project and due to ethical issues, the following delimitations were made.

- The project concerns passengers in the front seat only.
- The user studies are performed in a Volvo S90, 2017.
- No old participants younger than 65 years old are included in the project.
- No young participants outside the range of 25 - 30 years of age are included in the project.
- The project does not include investigating entering/exiting the vehicle.
- The project is limited to static user studies, meaning that no dynamic user studies travelling by car will be performed with subjects.

1.5 Thesis outline
The outline of the thesis can be seen in figure 1.1. The first chapter describes background, aim, research questions and delimitations of the project. Chapter 2 describes a theoretical framework for the thesis. Chapter 3 describes the methods used during the project and the implementation of the methods. Chapter 4 – 7 describe the results of the project and chapter 8 describes design guidelines. In chapter 9 the results, methods and implementation are discussed. In chapter 10 conclusions are drawn based on the findings and the research questions are answered.

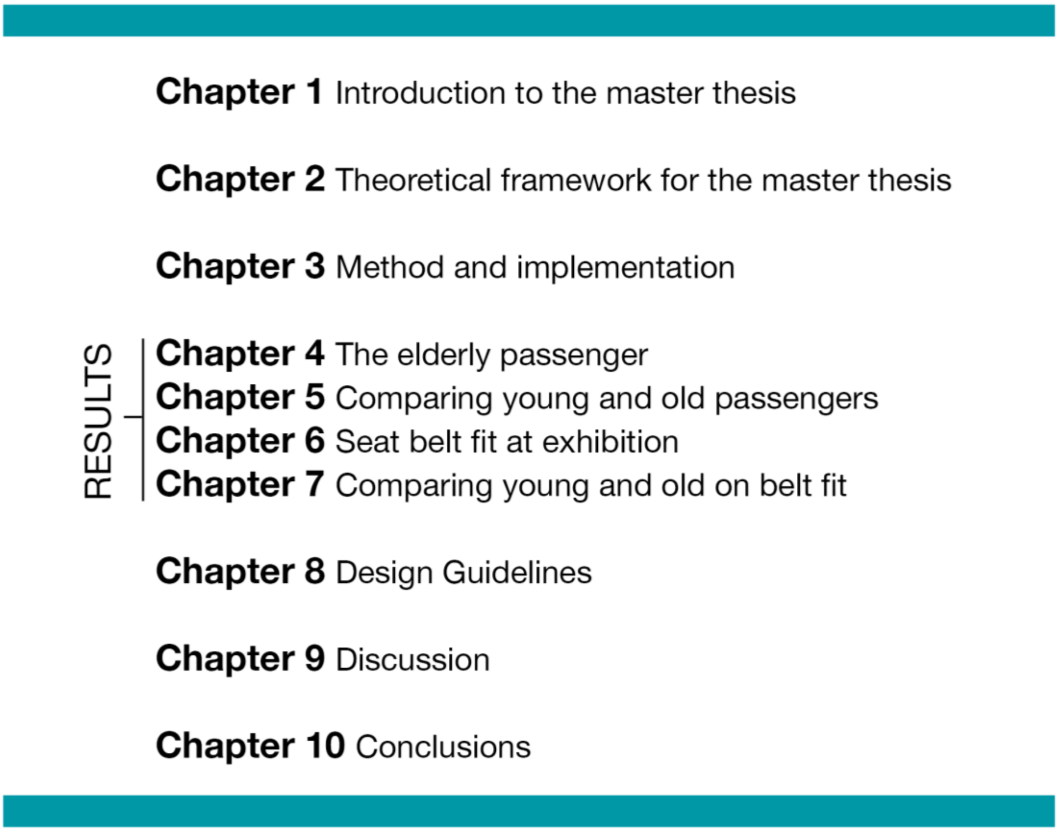


Figure 1.1 – Thesis outline.

2. Theoretical framework

This chapter describes the review of previous research and literature used in this master thesis. Information that was found relevant for the thesis was gathered and documented below.

2.1. Body changes associated with aging

The older population differs from the younger regarding musculoskeletal characteristics and physical abilities. Body size, range of motion and joint flexibility as well as strength are the major categories affecting the elderly population compared to the younger population. The older population have decreased flexibility, body height, sitting height, eye height, atrophy of arm length, compression and thinning of the intervertebral discs of the spinal cord (Peacock & Karkowski, 1993).

2.1.1 Deteriorations associated with aging

Among people around 70 years old, every third woman and every sixth man suffer from Osteoporosis. Osteoporosis weakens the skeleton and leads to an increased risk for fractures. Most common are fractures in wrists, hips, vertebrae, and upper arms (Friedmann, 2018). According to Peacock and Karkowski (1993), 50% of the population over 70 years old have arthritis. Arthritis is more common among women than men. Arthritis leads to decreased mobility and pain. It affects different joints. For example, it can affect the knee, hip or finger joints. Arthritis in the finger joints hampers the ability to grip something with full force and leads to that the fingers become stiff and hard to move (Martinez, 2015). Another common problem among elderly is joint pain. Joint pain can be a result of infections, aging deterioration, and inflammations. It can lead to stiff joints that are hard to move, pain and swelling (Brydolf, 2016). Shoulder range of motion is another factor that decrease linearly from the sixth to ninth decade, statistically significant for abduction and external rotation. Women are found to have significant greater range of motion than men for flexion, abduction, and internal rotation (Fiebert, Downey & Stackpole Brown, 2009).

Pressure pain thresholds have also been found to decrease with age. Sensitivity to pressure pain was found markedly enhanced in elderly, aged around 70 years old, compared to young people, aged around 20 years old (Lautenbacher, Kunz, Strate, Nielsen & Arendt-Nielsen, 2005). lllab, Robinsonb, Myersb, and Fillingimc (1998), found both pain threshold and tolerance lower for women than for men.

Aging has furthermore been found to have a degenerative effect on hand function, including hand and finger strength, ability to control submaximal pinch force, maintain a steady precision pinch posture, manual speed, and hand sensation. Compared with young subjects, older people have been found to have 30 % weaker handgrip force. The maximal pinch force was found to be 26% lower among old subjects compared to young. The ability to maintain steady submaximal pinch force and a precision pinch posture was also found significantly less among old subjects compared to young. Furthermore, the decrease in the ability to maintain steady submaximal pinch force was found more pronounced in women than men (Ranganathan, Siemionow, Sahgal, & Yue, 2001). Kallman, Plato and Tobin (1990), found a curvilinear decline in grip-strength with increasing age. The average rates of decline of grip becomes increasingly greater with advancing age. This loss of strength is best explained by physiological aging. A high correlation between forearm circumference and grip strength have been found. However, other age-related factors are important determinants of grip strength (Kallman et al., 1990).

2.1.2 Changes in posture

Flatter and more kyphotic spinal curves are observed in both sexes over 60 years old (Peacock & Karwowski, 1993). Lordotic postures results in less disc pressure than slumped, kyphotic postures (Gkikas, 2013). Quek, Pua, Clark and Bryant (2013), found thoracic kyphosis associated with a forward head posture. The forward head posture was assessed via the craniovertebral angle (CVA) (i.e., the angle between the horizontal line passing through C7 and a line extending from the tragus of the ear to C7). A lesser CVA indicated greater forward head posture (Quek et al. 2013). Among elderly persons, 20-40 % have kyphotic spinal curves. The kyphotic spinal curve is considered to be affected by osteoporosis and compression fractures. However, only a third of the people having kyphotic spinal curves have this. Other explanations are changes in posture, wear of the intervertebral discs, muscle weakening and loss of elastic tissue in the ligaments of the back among elderly (Johannessen, 2014).

2.1.3 Changes in body composition

People over 60 years old compared to people younger than 60 years old are more likely to have very high BFMI (body fat mass index). Body mass index (BMI) does not discriminate body fat from fat free mass or determine changes in these parameters with aging and physical activity (Kyle, Morabia, Schutz, & Pichard, 2004). Goodman-Gruen and Barrett-Connor (1996), studied sex differences in measures of body fat and body fat distribution in the elderly. It was found that upper body obesity is more common among men than women, even in old age. Furthermore, it was found that women had a greater percentage of leg and trunk fat than men. Larsson et al. (2015), studied body composition through adult life on Swedish reference data and found that BMI (Body mass index) and FM (fat mass), were higher among older age groups compared to younger ones. FFM (fat free mass) was found to remain stable up to 60 years of age and was lower among the 75 years of age. However, for women FFM was found lower from age 60. Shimokata, Tobin, Muller, Elahi, Coon, & Andres (1989), studied five anthropometric ratios for 1179 men and women aged 17-96 in Baltimore, USA. In general, the age patterns displayed progressive trends towards increasing upper and central body fat deposition with age for both men and women.

According to Baumgartner, Waters, Gallagher, Morley, and Garry (1999), elderly men and women lose muscle mass and strength with increasing age. This was found especially accelerated after the age of 65 years old. The muscle loss was found associated to physical activity in both men and women. However, sex hormone status was found to be an important factor for the muscle loss in men. According to Peacock and Karkowski (1993), the strength of 65-year old’s is 75% of normal 20-year old’s. Kallman et al. (1990), found a 30-40% decline in back, leg and arm strength, from age 30 to 80.

2. 2 Belt fit

The 3-point seat belt consists of two parts; the shoulder and lap belt. The shoulder belt controls the kinematics of the upper body; torso and head. The lap belt should restrain and load the force on the pelvic bone. Both parts should fit the occupant well to achieve overall good belt fit. The seat belt needs to fit a wide variety of different body sizes. Reed, Ebert-Hamilton, and Rupp (2012), have found that occupants with a higher BMI positioned the belt higher on the abdomen and more forward relative the pelvis than those with lower BMI. According to Reed, Ebert, and Hallman (2013), body mass index has been found to be the most important factor influencing belt fit and is associated with a longer length of webbing pulled out from the reactor, regardless of seat position and stature. Furthermore Fong, Keay, Coxon, Clarke and Brown (2016), found suboptimal fit to be associated with being female or having a high BMI.

2.2.1 Shoulder belt fit

Referring to previous studies (Reed et al., 2013) (Fong et al., 2016) shoulder belt fit is judged good if the distance between the inboard edge of the belt relative to the torso centerline at the height of the suprasternal notch is as short as possible and the belt is cutting the mid portion of the clavicle. The shoulder belt controls the kinematics of the upper body; torso and head. In terms of thoracic injury protection, the shoulder belt protects the occupant best when the contact area between the belt and bony structure is the greatest. This is with the assumption that the force transferred from the shoulder belt to the skeleton structures are lower since it is distributed over a larger area.

2.2.2 Lap belt fit

Referring to previous studies (Reed et al., 2013) and (Fong et al., 2016), lap belt fit is judged good if the belt is positioned lower on the abdominal, below the anterior-superior iliac spines (ASIS) and in contact with the upper thigh. Furthermore, the distance between the lap belt and the pelvic bone should be as short as possible to reduce the distance the belt has to travel before it grabs the bone during a frontal crash. Any slipping motion of the lap belt with respect to the pelvis and abdomen area is referred to as submarining. This may cause serious injuries on the abdominal area during a frontal crash. There are three categories which have an influence on the occurrence and consequences of submarining. The first is restraint device parameters such as angulation of the lap belt. The second is occupant parameters such as obesity, posture and posture change due to slouching. The third is occupant near-environment parameters such as geometrical and mechanical characteristics of the seat and the seat belt (Biard, Cesari, & Derrien, 1987). During a frontal crash the lap belt should restrain and load the force on the pelvic bone. If the lap belt is placed wrong, there is an increased risk of submarining. Placing the seat belt higher on the abdomen due to high BMI increases the risk of a slipping motion of the lap belt in relation to the pelvic bone.

2.3 Seat belt use and crash protection among elderly

Seat belts effectively reduce the risk of death and injury in different types of crashes (Kahane, 2000; Glassbrenner & Starnes, 2009; Ridella, Rupp & Poland, 2012). The seat belt effectively protects occupants in various seating positions and for a wide range of individual characteristics from children to older adults (Elliott, Kallan, Durbin, & Winston, 2006; Glassbrenner & Starnes, 2009). According to Morris, Welsh, and Hassan (2003), older passengers are much more likely to be killed or seriously injured compared to younger passengers in frontal crashes. However, young passengers are as equally likely to be killed in struck-side crashes compared to the older group. Older passengers have been found to sustain more serious injuries to the chest region, particularly rib fractures, in frontal crashes compared to younger passengers. This is more common among older woman (Ridella et al., 2012). Since every third woman and every sixth man suffers from Osteoporosis, which weakens the skeleton, there is an increased risk of fractures for elderly (Friedmann, 2018). Bone strength and fracture tolerance are associated with age and therefore the consequence of an assault is more likely to be serious on older occupants compared to younger (Dejammes & Ramet, 1996; Evans, 1991; Mackey, 1989, Viano, Culver, Evans, Frick, & Scott, 1989). According to Morris et al. (2003), there has been a study which concluded that older people could withstand a chest load of 5,000 Newtons compared to young people who could withstand a chest load of 8,000 Newtons. Older occupants may also be at greater risk of abdominal injury than younger occupants (Yaguchi, Omoda, Ono, Masuda & Onda, 2011).

2.3.1 Belt fit among elderly

Only a few studies have been done on how aging affects seat belt fit in cars. According to Fong et al. (2016), there are problems in achieving a comfortable and good seat belt fit among elderly drivers aged 75 years or older. Seat belt fit has been found associated with body shape, in particular high BMI and gender, which may also have a negative impact on crash protection (Fong et al., 2016). Regarding seat belt fit there seems to be a mismatch between the users' anthropometry and seat belt fit (Coxon, Keay, Fong, Clarke, & Brown, 2014). Older women have been found more likely to demonstrate poor lap belt fit regardless of BMI. This likely reflects differences in age-related fat distribution between older men and women. Furthermore, poor lap and shoulder belt fit have been observed relatively common among elderly regardless of BMI. This indicate that there are age-related changes in the distribution of body fat which are not adequately captured by BMI (Fong et al., 2016). Based on the result from the two studies (Fong et al., 2016; Coxon et al., 2014), using solutions such as D-ring, seat base, back and lumbar support adjustments may help improving seat belt fit. In previous studies participants have not been asked about their own perception of belt fit. According to Fong et al. (2016), the occupants perception might be worth including in future studies because it might provide insight about the perception of discomfort and repositioning behaviors. Furthermore, it might also provide interesting information about what the occupants think represent good belt fit.

Brown, Coxon, Fong, Clarke, Rogers, and Keay, (2016) examined functional morbidities associated to older drivers' behaviors in vehicles. It was found that repositioning of the seat belt was more likely the more musculoskeletal morbidities an older driver had. It was also found that seat accessory use among the elderly were more common the more morbidities, of any type, they had. These findings suggest that elderly, especially those with conditions that impact physical function, need to become more aware of the importance of achieving and maintaining a good seat belt fit (Brown et al., 2016). Reed et al. (2013), found that the positioning of the lap belt was 18 mm further forward relative to the pelvis when looking at an increase in age from 20 to 80 years. Reed et al. (2013), also suggest that further research is needed to consider belt fit for older and obese occupants. Furthermore, Reed et al. (2013), found that age and BMI (body mass index), had significant effects on both posture and belt fit.

2.4 Passenger comfort

Comfort is essential for reducing fatigue and for avoiding musculoskeletal disorders. Comfort is affected by several different factors such as seat shape and firmness. To accommodate different body types and preferences it is important that the seat and seat belt can be adjusted (Peacock & Karwowski, 1993). Elderly occupants have been found to use add-on accessories such as comfort pads for improving comfort. It is important to understand the reasons for this and also important to better understanding the factors impacting comfort of elderly to ensure optimum crash protection (Fong et al., 2016).

2.4.1 Factors influencing comfort and essential adjustments

Both the seat belt and seat influence the comfort. Comfort is also affected by the possibility to adjust the seat and seat belt to fit the needs and preferences of the occupant.

Seat belt

Fong et al. (2016), studied seat belt use and fit among 367 participants aged 75 or older. 90% of the participants in the study thought the seat belt was comfortable. However, one third of the participants had some experience of seat belt related discomfort. The most commonly encountered discomfort was the shoulder belt being in contact with the neck. Furthermore, one-fifth of the participants reported that they sometimes reposition the seat belt to improve comfort. The study showed different results between genders. 31% of the females repositioned their seat belt for improving the comfort compared to 13% of the males. Participants who reported discomfort, most often repositioned the seat belt. These participants also did not use the D-ring adjustment or showed poor shoulder belt fit. Furthermore, one third of the participants did not know if their car had an adjustable D-ring height (Fong et al., 2016).

Seat

Seat comfort includes both static and dynamic comfort. Static comfort involves the stiffness of the cushion and back, seat contour and climate. Dynamic comfort involves cushion and back stiffness as well as adjustments by the occupant to change position. Higher seat stiffness equals higher frequencies transmitted and lower stiffness of the seat equals that the pressure is distributed over a greater area. Seat stiffness and materials should enhance the occupants' ability to change position. Usually, regarding the lumbar support, a stiff, well defined support is preferred initially and then after three hours, this is reversed. To accommodate for different preferences and spinal structures an adjustable lumbar height support is required (Peacock & Karwowski, 1993).

The goal of increasing comfort is to avoid musculoskeletal disorders and reduce fatigue. This is affected by seat shape and upholstery characteristics such as contour and firmness. It is also affected by covering materials, seat bottom height, seat bottom tilt, seat back angle, seat contour, head rest, lumbar support, and armrests. These factors contribute to dynamic comfort (Harrison, Harrison, Croft, Harrison, & Troyanovich, 2000). Grujicic, Pandurangan, Arakere, Bell, He and Xie (2009), found that various seat adjustments such as backrest inclination and lumbar support etc. can have a complex influence on muscle activation, joint forces and soft-tissue contact, which affect comfort perception and the feel of fatigue. To accommodate different body types, the car seat angle, vertical height, and horizontal position should be adjustable. Height adjustable lumbar support is for example a necessity (Peacock & Karwowski, 1993). The headrest is also a concern in seat comfort. It should be adjustable, both vertically and horizontally. For instance, it is uncomfortable to sit in a car seat with a headrest that pushes the head forward which results in an anterior translated position. The head rest should have a convex surface and a cervical support similar to the lumbar support. It should also have a soft enough foam density for comfort when fully leaning the head back for rest (Harrison et al., 2000). Another factor that has been found important for physical and psychological comfort is lateral space. In a bench or split seat, the width is primarily for psychological comfort (Peacock & Karwowski, 1993).

Ride comfort has also been associated with vibration since 1940. Exposure to vibration has been linked to lower back pain the past five decades. The seat design must therefore consider the vehicle suspension system and the vibration transmitted to the seated occupant (Peacock & Karwowski, 1993). Since lower back pain, according to Kroemer (2006), is common among elderly people considering this when designing for accommodating elderly might be especially important. The majority of physiological effects from vibration occur below 20 Hz. The trend has been to reduce these vibrations by reducing the amount of springs in the seat and by using a thick firm foam. However, also adding shock absorbers, that eliminate certain frequencies, has been shown to be even better (Harrison et al., 2000).

2.4.2 Occupant posture

The contours of the seat largely determine posture in the seat. There is both a loaded (seat carrying occupant) and an unloaded seat contour. The deflection of the seat surface from loaded to unloaded affects pressure distribution in the seat. The change in contour when an occupant sits in the seat is the measure of stiffness in an automotive setting. When an occupant changes position in the seat and when adjustments to the seat are made, the loaded contour changes. Thus, the contour is a dynamic parameter in seat design. A deflection of maximum 75 mm in the seat cushion is recommended since it will provide a firm surface on which positions can be changed and since too much deflection restrict position changes as well as increases muscle effort required for it. Furthermore, to avoid occlusion of fluids in the legs, the cushion should be contoured and soft at the “waterfall” under the knees. In conclusion, features that assist the occupant in changing position will increase comfort. The seat should also support a variety of seated postures. Highly contoured seats cannot accommodate differences between people or easily allow change of position. Thus, seats should be designed with gentle contours and firm cushion (Peacock & Karkowski, 1993).

When seated with knees extended 90-125 degrees, the hamstrings are stretched which pulls the pelvis backwards. This rotates the pelvis rearwards which flattens the lumbar curve. To stabilize the lumbar, the psoas muscle is engaged. This increases lordosis, but it also increases disc pressure. Thus, car seats should support the pelvis and reduce postural stress and optimize muscular effort. Comfortable support for many postures is essential so that occupants can relieve stress by changing posture (Peacock & Karkowski, 1993). The backrest should support the lumbar spine and the weight of the trunk. If it doesn't, there will be a loss of lordosis, increasing disc pressure, straining on the spinal ligaments and gluteal muscles, and increasing kyphosis. This slouched posture could be exacerbated by design elements such as low headroom space or a too long seat cushion length (Gkikas, 2013).

2.4.3 Accessory use among elderly

Elderly occupants have been found to use accessories in the form belt comfort pads and cushions for the seat base, back and headrest in their cars. In a study of seat belt use and fit among 367 elderly drivers, it was found that one-fifth of these used some kind of add-on accessory. 9% used a pad or cushion on the seat belt and 17% percent used an accessory for the seat. Twenty-one cases were also found where participants were using more than one seat belt or seat accessory. Seat belt pads were found used more often among short elderly drivers and seat cushion accessories were used more often among participants who reported seat belt comfort problems. There is a need to understand the reasons for this and also a need for better understanding the factors impacting comfort of elderly to ensure optimum crash protection (Fong et al., 2016). According to Coxon et al. (2014), the use of add-on accessories may negatively impact crash protection because of the induced slack it leads to in the system. Instead of using accessories, other solutions such as use of adjustable D-rings, seat base, lumbar and back support should be encouraged.

2.5 Summary of theoretical framework

Based on the theoretical framework provided in this chapter, the following summary list were findings considered especially important:

Body changes

- Elderly occupants have reduced tolerance to impact compared to young occupants and are more likely to sustain injury in frontal car crashes.
- The older population differs from the younger regarding musculoskeletal characteristics and physical abilities. Body size, range of motion and joint flexibility as well as strength are the major categories affecting the elderly population compared to the younger population.
- Among people around 70 years old, every third woman and every sixth man suffer from Osteoporosis which weakens the skeleton.
- 50% of the population over 70 years old have arthritis. Arthritis is more common among women than men. Arthritis leads to decreased mobility and pain.
- Sensitivity to pressure pain was found markedly enhanced in elderly, aged around 70 years old, compared to younger, aged around 20 years old.
- Among elderly persons, 20-40 % have kyphotic spinal curves and postures which results in more disc pressure than lordotic postures.
- There are age-related changes in the distribution of body fat which are not adequately captured by BMI.
- There is a difference in age-related fat distribution between older men and women.
- Upper body obesity is more common among men than women, and women have been found to have a greater percentage of leg and trunk fat than men.
- FFM (fat free mass) have been found lower among elderly women from 60 years and lower among men from 75 years.
- BMI and FM (fat mass) have been found higher among older age groups compared to young.

- Elderly men and women lose muscle mass and strength with increasing age, with accelerating rate after age 65 years old.
- A 30-40% decline in back, leg and arm strength from age 30 to 80 have been found.

Seat belt fit

- Previous studies define shoulder belt fit as good when the distance between the inboard edge of the belt relative to the torso centerline at the height of the suprasternal notch is as short as possible and the belt is cutting the mid portion of the clavicle.
- Previous studies define lap belt fit as good when the belt is positioned lower on the abdominal, below the anterior-superior iliac spines (ASIS) and in contact with the upper thigh. Furthermore, the distance between the lap belt and the pelvic bone should be as short as possible to reduce the distance the belt has to travel before it grabs the bone during a frontal crash.
- Seat belt fit have been found associated with body shape, in particular high BMI and gender.
- BMI (body mass index) have previously been found to be the most important factor influencing seat belt fit.
- Poor lap and shoulder belt fit have been observed relatively common among elderly. regardless of BMI. This indicate that there are age-related changes in the distribution of body fat which are not adequately captured by BMI.
- Seat belts effectively reduce the risk of death and injury in different types of crashes.
- Compared to younger, older occupants involved in crashes have a greater risk of thoracic injuries, rib fraction in particular, induced by the seat belt.
- Previous studies have stated that it might be worth including the occupants' perception of seat belt fit to provide information about what the occupants think represent good belt fit.

Comfort

- To reduce fatigue and avoid musculoskeletal disorders, comfort is essential. To accommodate different body types and preferences it is important that the seat and seat belt can be adjusted.
- The most commonly encountered discomfort has previously been found to be the shoulder belt being in contact with the neck.
- Elderly occupants have been found to sometimes reposition the seat belt to improve comfort.
- Seats should be designed with gentle contours and firm cushion that assist the occupant in changing position to increase comfort. Seats should also support a variety of seated postures.
- Elderly occupants have been found to use add-on accessories in the form belt comfort pads and cushions for the seat base, back and headrest in their cars.
- The use of add-on accessories may negatively impact crash protection because of the induced slack it leads to in the system.

- There is a need to understand the reasons for the accessory use among elderly and also a need for better understanding the factors impacting comfort of elderly to ensure optimum crash protection.

3. Method and Implementation

This chapter describes how the master thesis was carried out and the methodology that was used. This includes how the project was planned and managed, background study, data collection methods, planning user studies, designing user studies, implementing user studies, data compilation and analysis, and creation of guidelines.

3.1 Project process and planning

When planning the thesis, a process was developed for the project. The process included six major steps; Literature study, Designing user studies, Pilot testing, User studies, Analysis and Design guidelines. Iterations were made throughout the whole process, but mostly during the first three steps where ideas were pilot tested and evaluated. The process can be seen in figure 3.1.

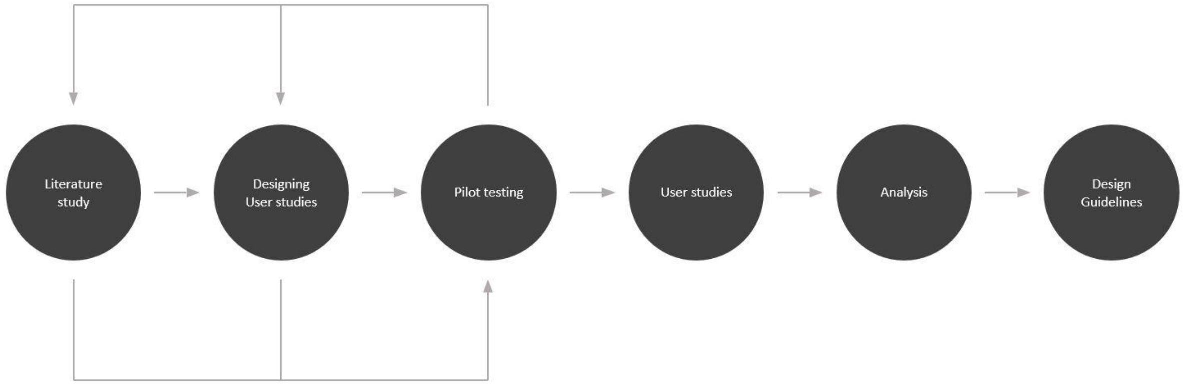


Figure 3.1 - Visualization of the process used in this project.

The project was initiated by the creation of a project plan where the aim, objectives and demarcations were formulated. A Work Breakdown Structure (WBS) was created for achieving an overview of the project. According to Lilliesköld and Eriksson (2004), a WBS is used for breaking down the project into several work packages and tasks and ordering them in a hieratical structure. When the WBS was created, a network diagram was created for illustrating dependencies and sequences for the different activities that were to be carried out in the project. According to Jansson and Ljung (2004), a network diagram is created by placing work packages in the correct order that they should be carried out and connecting them with arrows that illustrate which work packages that depend on each other. Based on the WBS and the network diagram it was possible to create a GANTT-schedule. According to Jansson and Ljung (2004), a GANTT-schedule display an overview of when the work packages should be carried out on a timeline. The GANTT-schedule was in this project created to describe this as well as important dates for meetings and events. The GANTT-schedule can be seen in Appendix 1.

3.2 Background study

The background study of this project consisted of studying previous research, literature and other material that would or could be of help during the course of the project. According to Martin and Hanington (2012), literature reviews are a useful component of design projects for collecting and synthesizing research on a given topic. In this project previous research and literature in relevant areas were studied for achieving a broad understanding of the central topics; Belt fit, comfort, safety and aging deteriorations. Previous research was studied for identifying what have been done in the area and for identifying knowledge gaps to investigate further. Literature was studied for finding relevant methods that could be appropriate for user studies. Information was primarily collected from academic literature.

When information within the different areas was gathered, the next step was to analyze it in order to find patterns. This was done by compiling the information into different clusters using Affinity Diagramming, described by Martin and Hanington (2012), (figure 3.2).

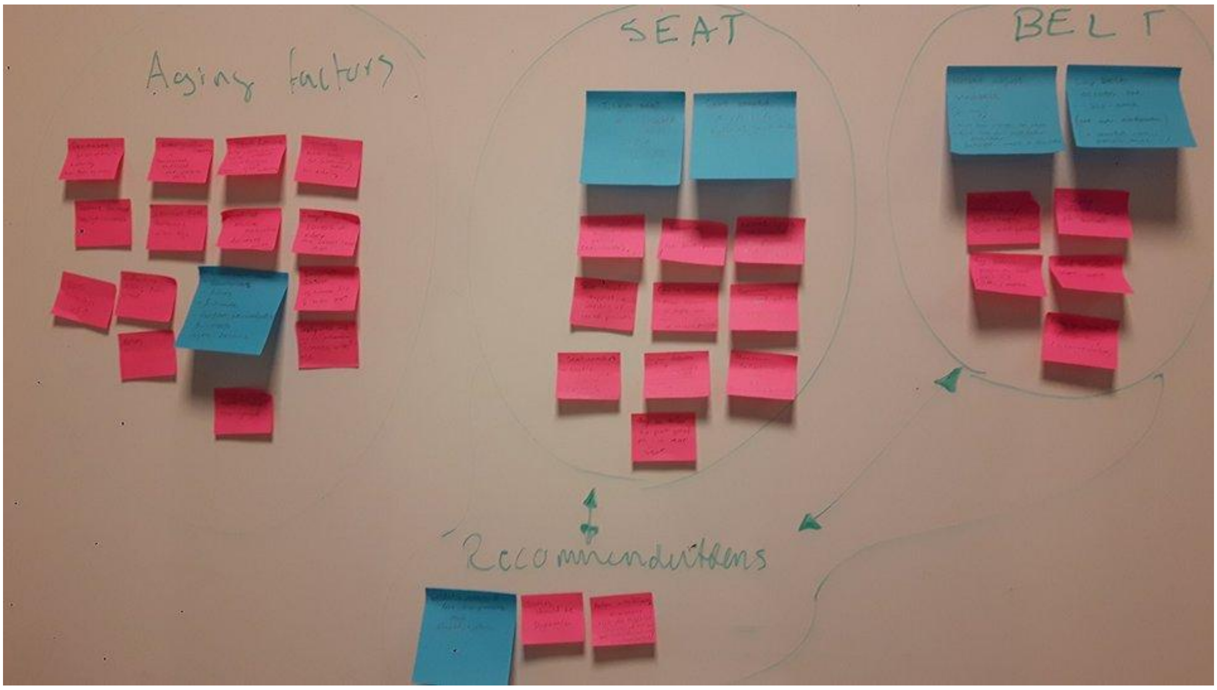


Figure 3.2 - Picture showing compiled information during the Affinity Diagramming.

3.3 Data collection methods

To collect both subjective and objective data, different data collection methods were used. Subjective data was collected through structured interviews. Objective data was collected by measuring body data, different distances and angles in a test car. Data was also collected by taking photographs of the participants sitting in the passenger seat of a car.

3.3.1 Structured interviews

Interviews are fundamental research methods for direct contact with participants. They give the possibility to collect personal experience, opinions, perceptions, and attitudes. Interviews may be structured or relatively unstructured. Structured interviews follow a script of questions and are easy to control in terms of timekeeping, as well as are relatively easy to analyze. Unstructured interviews have the advantage of being conversational and comfortable for the participants. However, they rely on the researcher's ability to guide the session and collect the necessary information within a certain period (Martin & Hanington, 2012).

In this project, structured interviews were used for collecting subjective data on how the intended user group and the reference user group experience comfort and safety in today's cars. A structured interview technique was chosen because the studies were comparative. Thus, it was important to give the same condition for all participants. The interviews were conducted during the user studies. To facilitate structuring the interviews and to facilitate analyzing the results, Google form was used.

3.3.2 Observations and objective data collection

Observations give the possibility to get insights on people's behaviors and interactions. Observational methods may be characterized by their degree of formality based on recording methods, their intended use and on the level of pre-structuring of the observations. Structured observations utilize pre-structures such as worksheets or checklists (Martin & Hanington, 2012).

In this project structured observations were used to collect data on how aging affect seat belt fit for passengers in cars. Each participant was photographed during the user studies. Using the photographs, it was possible to observe and assess the belt fit of each participant. Body related data and adjustments made to the seat were measured and documented for each participant, resulting in objective data. The assessments of the photographs and the objective data were then used together for analyzing the results.

3.4 Defining aim for user studies

Two different static user studies with a Volvo S90, 2017 were planned to investigate how older people sit, wear the seat belt, and perceive comfort as passengers. The first in a facility at Lindholmen, Gothenburg, to investigate differences between old and young passengers in the same environment. The second at an exhibition with elderly visitors, to investigate differences within the older group. The aim for each of the two static user studies was first specified. The aims were elaborated in relation to the projects three research questions:

- How does aging affect seat belt fit and comfort for passengers in cars?
- How does the intended user group experience comfort in today's cars compared to a young reference group?
- How does elderly prefer to sit as passengers and how aware are elderly of safety related to seat belt fit compared to a young reference group?

3.4.1 Comparative user study

The comparative user study aimed at collecting data from elderly participants (70 years or older) and from young reference participants (25-30 years old). The collected data was used for comparing the two groups and the study was performed in a facility at Chalmers, Lindholmen. Two aims were formulated for the user study.

Aim 1: Seat belt fit

The first aim was to compare the old target group (70 years or older) to the young reference group (25-30 years old) on seat belt fit. The aim was also to investigate what factors that influenced the belt fit within the two groups. The data that was collected can be seen in table 3.1.

Table 3.1 – Data collection for aim 1.

Data collection		
Belt fit (defined and chosen seat position)	Posture and seat position (defined and chosen seat position)	Body measurements (Elderly and younger)

(Elderly and younger)	(Elderly and younger)	
• Shoulder belt position and angle. • Lap belt position and angle. • Location of ASIS in relation to the Lap belt.	• Document standing posture. • Measure chosen adjustments of the seat from defined position.	• Waist circumference. • Weight. • Stature. • Hip circumference.

Aim 2: Discomfort, accessory use, and adjustments

The second aim was to compare elderly to younger passengers on experiences of discomfort. This includes accessories, and adjustments used to improve comfort as well as previous experienced discomfort perceived in other cars. The data that was collected can be seen in table 3.2.

Table 3.2 – Data collection for aim 2.

Data collection		
Discomfort experience (in chosen seat position and previous experience) (elderly and younger)	Accessory use (previous use) (elderly and younger)	Adjustments (elderly and younger)
• Seat and seat belt. • What the reasons are for the discomfort. • Previous experiences of discomfort.	• Type of accessories • Accessory use frequency • Why the accessories are used.	• Commonly used adjustments.

3.4.2 User study at exhibition

The user study at the exhibition aimed at collecting data from a high number of elderly participants at an exhibition and it was carried out for three days. Two aims were formulated for the user study.

Aim 1: Seat belt fit

The first aim was to study the seat belt fit among elderly passengers (65 years or older). The aim was also to investigate what factors that influenced the belt fit within the group. The data that was collected can be seen in table 3.3.

Table 3.3 – Data collection for aim 1.

Data collection

Belt fit (defined and chosen seat position)	Posture and chosen position (defined and chosen seat position)	Body measurements
• Shoulder belt position and angle. • Lap belt position and angle. • Location of ASIS in relation to the upper edge of lap belt.	• Document standing posture. • Measure chosen adjustments of the seat from defined position.	• Waist circumference. • Weight. • Stature. • Hip circumference.

Aim 2: Discomfort and accessory use

The second aim was to study elderly passengers experience of discomfort related to the seat and seat belt during the user study, and to study their previous experience of discomfort. The aim was also to study what accessories that are commonly used among elderly, the frequency of which they are used and why they are used. The data that was collected can be seen in table 3.4.

Table 3.4 – Data collection for aim 2.

Data collection	
Discomfort experience (in chosen seat position and previous experience)	Accessory use (previous use)
• Seat and seat belt. • What the reasons are for the discomfort. • Previous experiences of discomfort.	• Type of accessories • Accessory use frequency • Why the accessories are used.

3.5 Planning user studies

When the aims for the two user studies were formulated, a plan was developed which describe how to define seat belt fit related parameters and how to recruit participants.

3.5.1 Defining belt fit parameters

The shoulder and lap belt were judged based on the theory from previous studies on belt fit described in “2.2 Belt fit”. Furthermore, the shoulder belt was judged on whether the upper part of it (the part reaching from the chest to the shoulder) was in contact with the body.

Shoulder belt

The shoulder belt was quantified on three criteria’s:

1. Shoulder belt position on the shoulder.

2. Shoulder belt position in relation to abdomen.
3. Shoulder belt contact from chest to shoulder.

Two measurements of the shoulder belt position were also documented:

1. Shoulder belt angle.
2. The distance from suprasternal notch to upper edge of the shoulder belt.

Regarding shoulder belt position on the shoulder, the belt could either be positioned over the mid portion of the shoulder, across the tip of the shoulder, in contact or close to the neck, or off the shoulder. Figure 3.3 describe these categories and how the belt approximately should be positioned to fit into each category. The shoulder belt position in relation to the abdomen was quantified as high, mid or low based on where it was positioned (figure 3.3). The shoulder belt contact from chest to shoulder was quantified as in contact or not in contact. If the shoulder belt was in contact with the body from the chest to the shoulder, it was judged as in contact (figure 3.4). The shoulder belt angle and the distance from suprasternal notch to upper edge of the shoulder belt was measured as in figure 3.5.

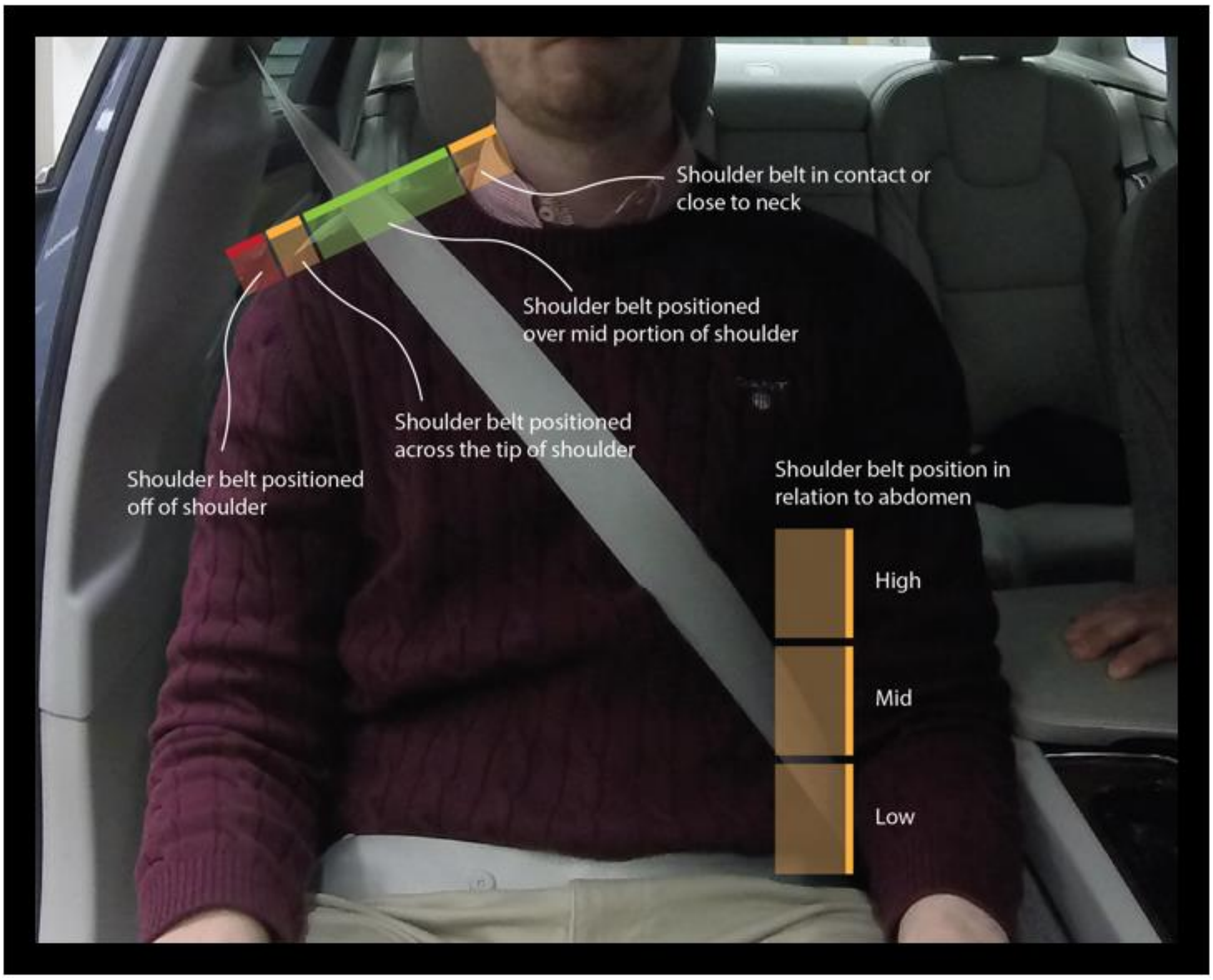


Figure 3.3 - Visualization describing how the position on the shoulder as well as on abdomen was judged.

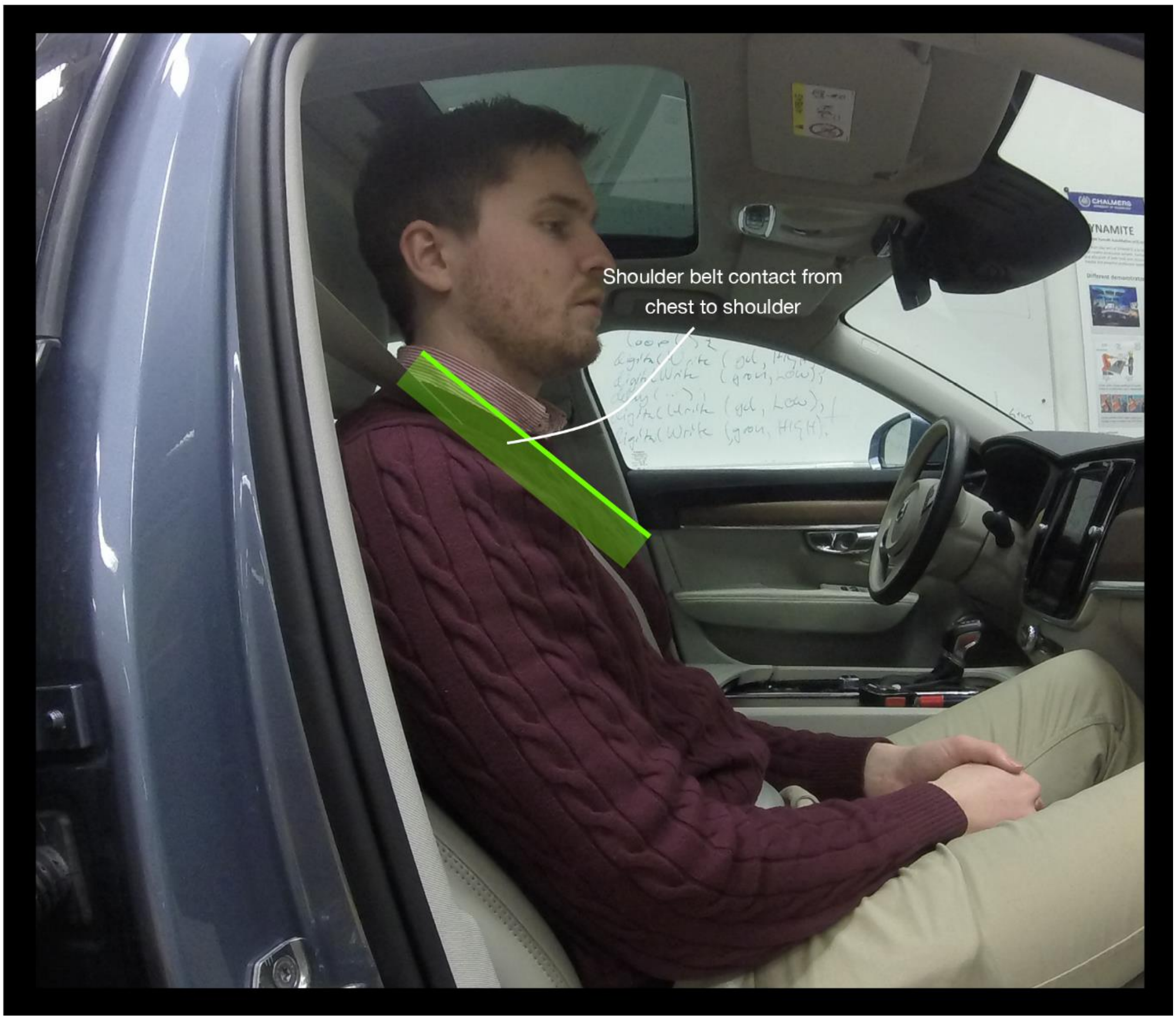


Figure 3.4 – Visualization describing the shoulder belt contact from chest to shoulder.

Figure 3.5 - Visualization of how the shoulder belt angle and distance between the suprasternal notch and the upper edge of the seat belt was measured.

Lap belt

The lap belt was quantified on one criteria:

1. Lap belt contact to upper thigh and position on the abdomen.

Two measurements of the lap belt position were also documented:

1. Anterior-superior iliac spines (ASIS) position in relation to the upper edge of the lap belt.
2. Lap belt angle.

Regarding, lap belt contact to upper thigh and position on the abdomen, the belt could either be positioned in contact with the upper thigh and lower on the abdomen or be positioned not in contact with the upper thigh and higher on the abdomen. The ASIS location in relation to the upper edge of the seat belt was measured and then classified as over, on or below the upper edge of the lap belt (figure 3.6). The lap belt angle was measured from the outlet of the lap belt to the center of the lap belt at the abdomen, as seen in figure 3.7. The lap belt angle was measured from a vertical line in the picture and should not be considered as the correct lap belt angle. The angle was used to compare the subjects rather than document the correct lap belt angle.

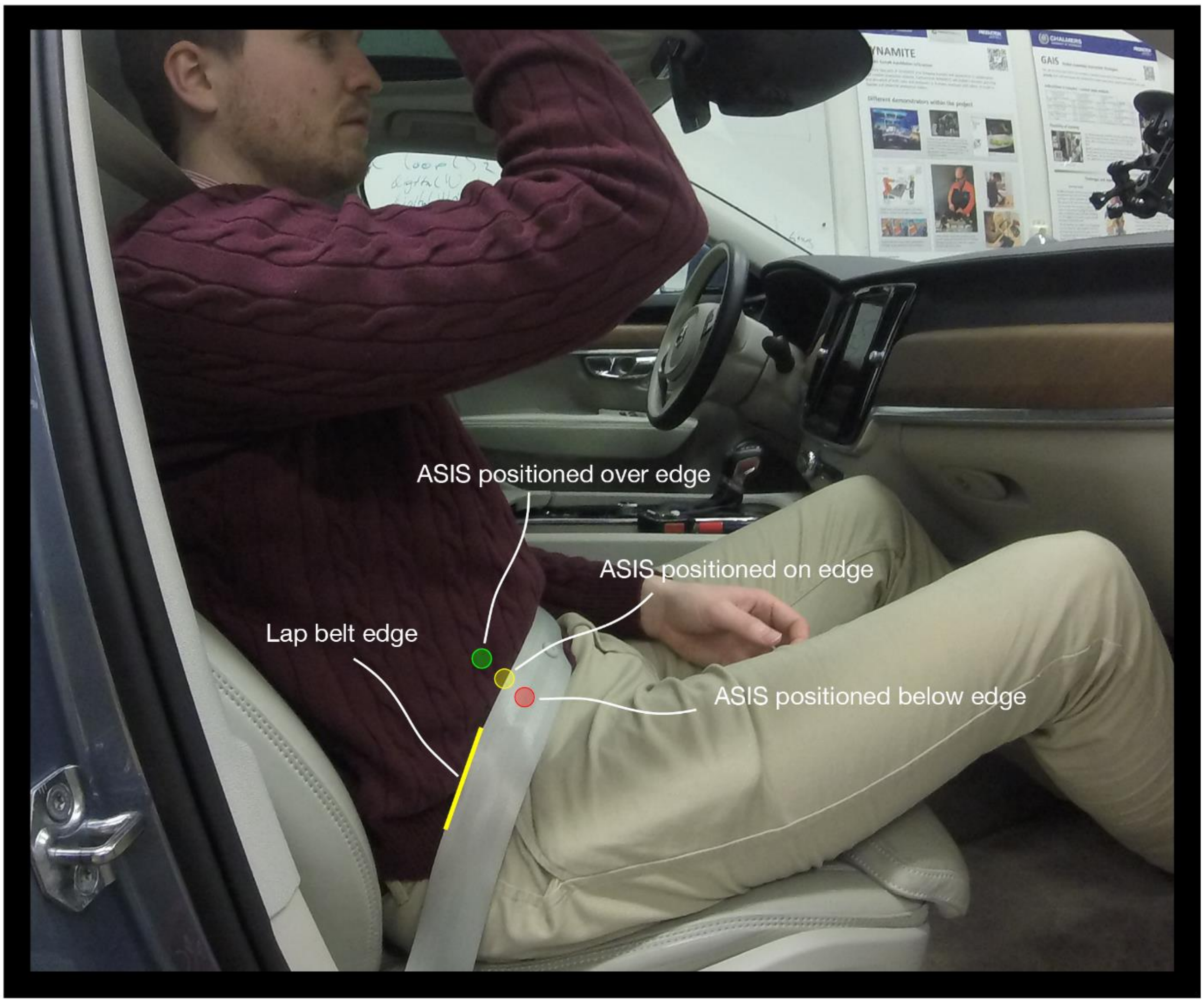


Figure 3.6 – Visualization describing how the ASIS location was considered over, on or below the upper lap belt edge.

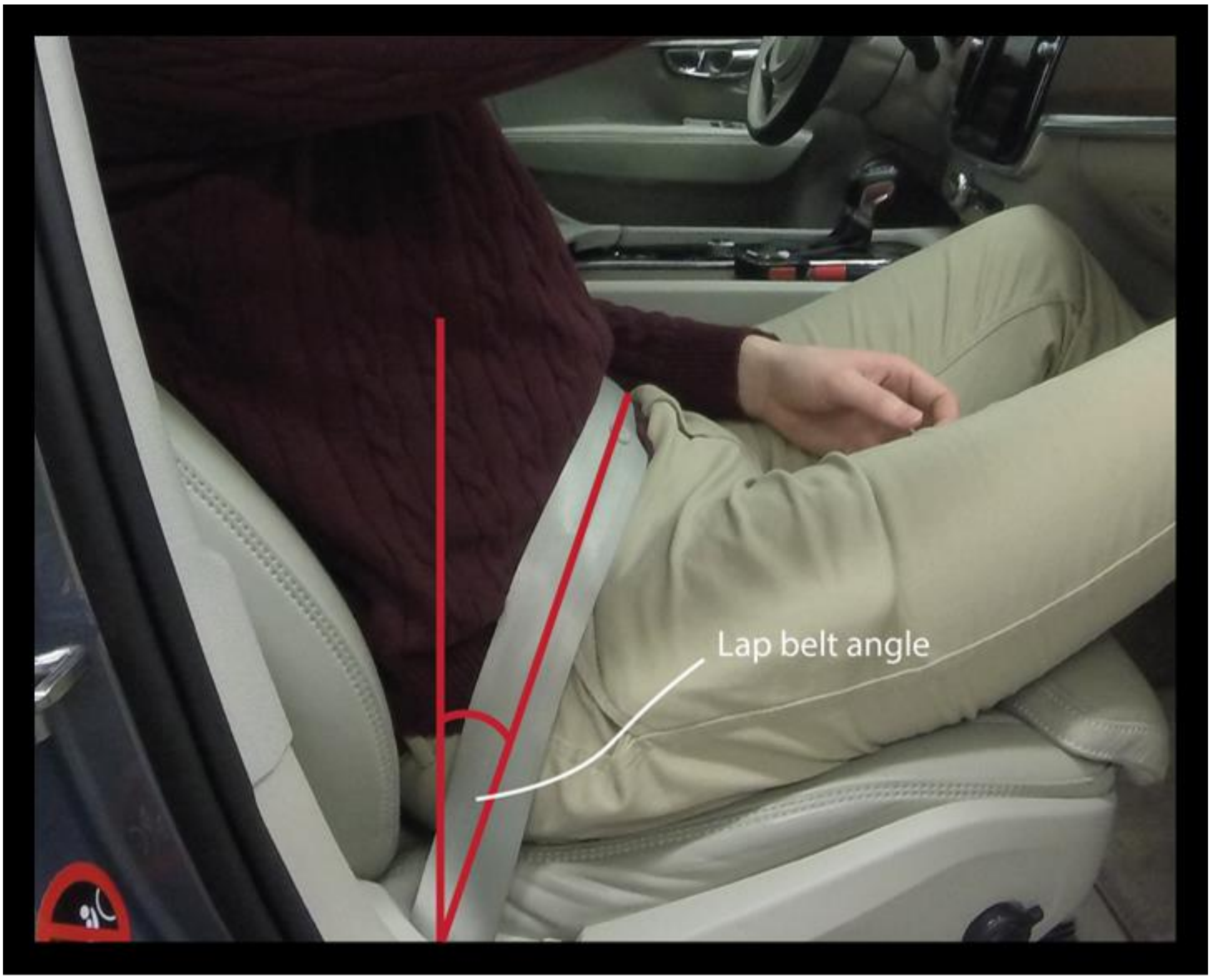


Figure 3.7 – Visualization of how the lap belt angle was measured.

3.5.2 Test participants

Regarding the number of participants, the aim was set to recruit about 10 elderly and 10 younger participants for the comparative user study. The exhibition (Seniormässan), usually have around 8000 visitors aged 65 years or older. The aim for the exhibition was set to recruit 60 participants.

The selection criteria for the test subjects for the comparative user study was elderly above 70 years of age. For the younger reference group, the criteria were young adults between 25-30 years old. To achieve the target number of participants during the exhibition the selection criteria was slightly lowered to 65 years or older

To recruit older participants for the comparative study an advertisement about the study was sent out to members within different Pensioners' Associations in Sweden. Members who wanted to participate could then report their interest. The advertisement asked for people to come one at the time or as couples. The younger participants were randomly picked and asked if they wanted to participate around the facility area.

3.6 Designing user studies

Designing the user studies required preparations and pilot testing. All necessary equipment had to be booked i.e. car, test participants, technical equipment, and facilities. The interview and the process of performing the study had to be developed, pilot tested and corrected if needed. Furthermore, different ways of measuring the chosen seat position, backrest angle, the ASIS position in relation to the seat belt and the posture of the participants had to be developed and pilot tested.

3.6.1 Layout of comparative user study

The layout was designed with the scenario of couples in mind. This was with the presumption that they might influence each other's answers if the interview took place so the other could hear the questions. Thus, a separate area was arranged away from the car where a waiting participant could sit without hearing or seeing the other participant. It was considered important to give the same conditions for every participant in the study. The layout consisted of three separate areas; one area where the significant other could wait while the other participated in the study, one area for body measurements and one area for the in-car interview and photo capturing while sitting in the passenger seat (figure 3.8). Since the car was used for other purposes during the project and sometimes had to be moved, the position of the car was marked on the floor using tape. Furthermore, this was also the case for the position of the camera tripod positioned outside the car. An agreement that ensured the participants anonymity was created and used for the old participants (Appendix 2). The young participants gave an oral consent based on provided information about the study.

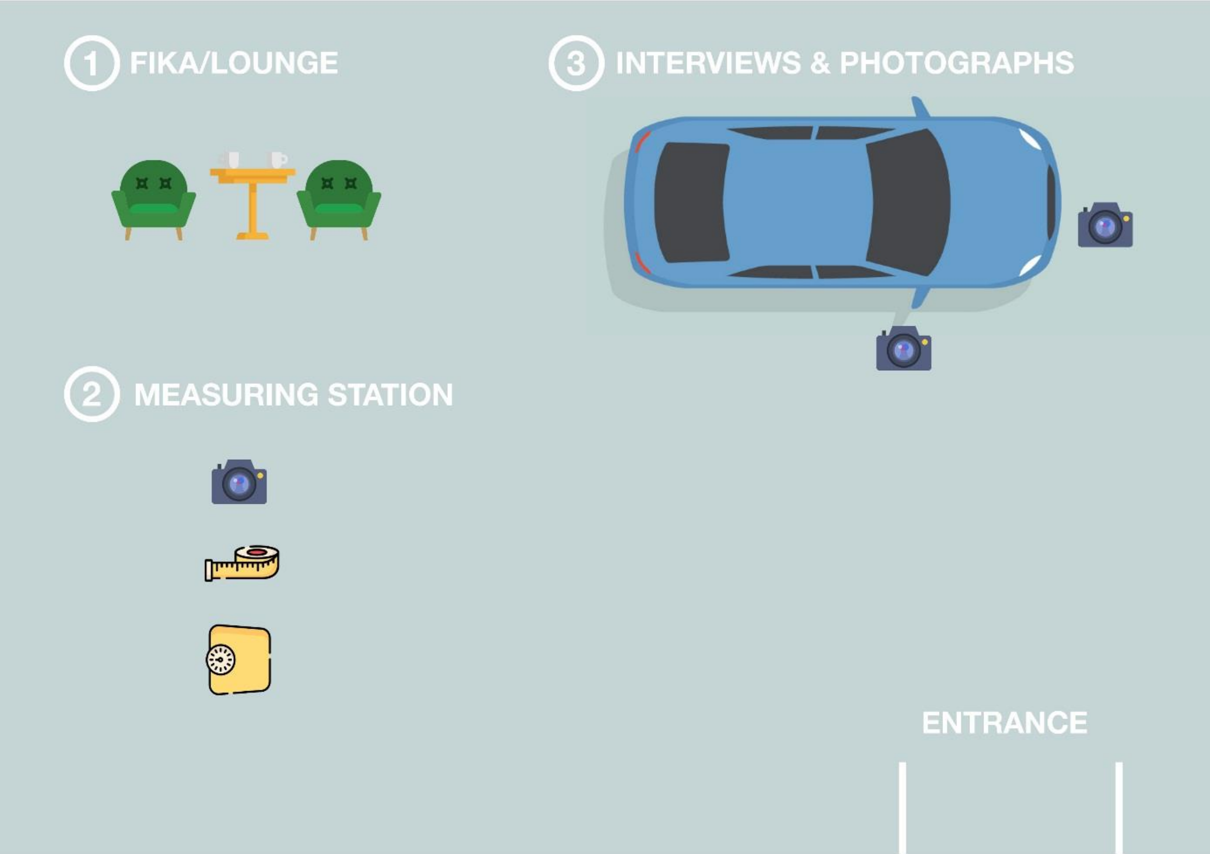


Figure 3.8 – The layout for the comparative user study.

3.6.2 Exhibition layout

The layout at the exhibition was designed to be similar to the layout of the comparative study. However, the size difference of the booth at the exhibition needed to be considered. The booth area was 5x4 meters and the size of the car was 2x5 meters. The car was placed to split the area in two. This made it possible to have two separate areas; one where information about the project was provided and one where the actual test and body measurements took place (Figure 3.9). Since the purpose was to perform the user study on belt fit in general and not to promote Volvo as a brand, it was decided to not mention or use any Volvo logos/posters in the booth. The reason for this was also to minimize the possible influence it might have had on the participants. Instead a poster was designed using the software Adobe Illustrator. The poster was printed in size A0. The poster included short information about the study, who could participate and a brief description of the procedure and time every participant had to commit (figure 3.10). Furthermore, information sheets were handed out, which described the study more in depth (Appendix 3). The participants gave their oral consent to participate in the study.

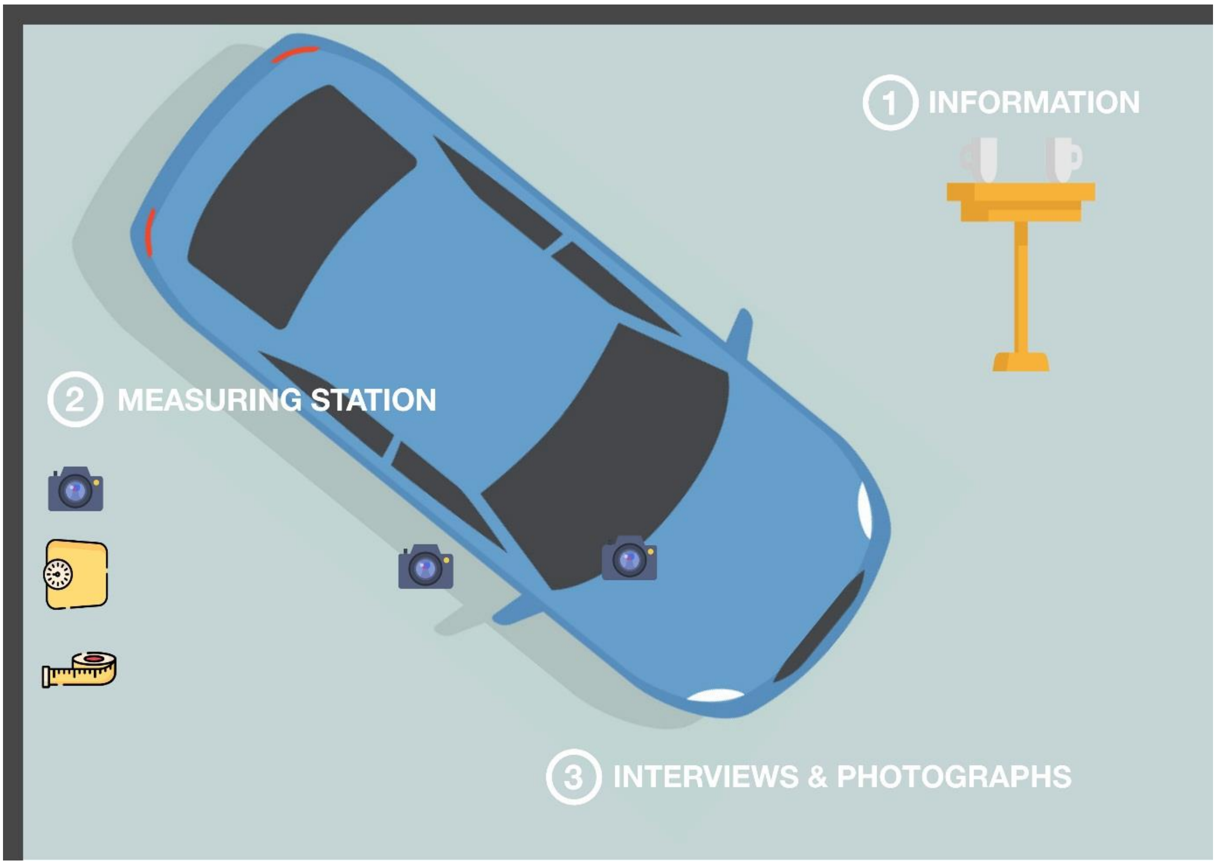


Figure 3.9 – The layout for the user study at the exhibition.

Figure 3.10 - The poster used to attract people at the exhibition.

3.6.3 Defined and chosen seat positioning

Defined seat position 1 & 2

To investigate body and age-related differences between the participants, a defined seat and seat belt position was needed for the user studies. This was the case, since all participants would then sit in the exact same position. It would then be possible to investigate what factors influenced the seat belt fit without being required to consider adjustments made to the seat. However, since Fong et al. (2016) and Coxon et al. (2014), suggested that using the D-ring adjustment may help improve seat belt fit, it was decided to use two different defined seat belt positions. The only difference between the two defined positions was the shoulder belt height. The seat itself would be positioned exactly the same in both positions. It was defined with a backrest angle of 22 degrees and a horizontal position 17 cm moved back from the furthest forward the seat could be positioned. This was done in order to find out if and how the shoulder belt height position affected how the shoulder belt was positioned between the two groups.

Defined seat position 1

The defined seat position 1 was defined as having the shoulder belt height adjusted to level 2 from the lowest possible level (figure 3.11).

Defined seat position 2

The defined seat position 2 was defined as having the shoulder belt height adjusted to the lowest possible level (figure 3.11).

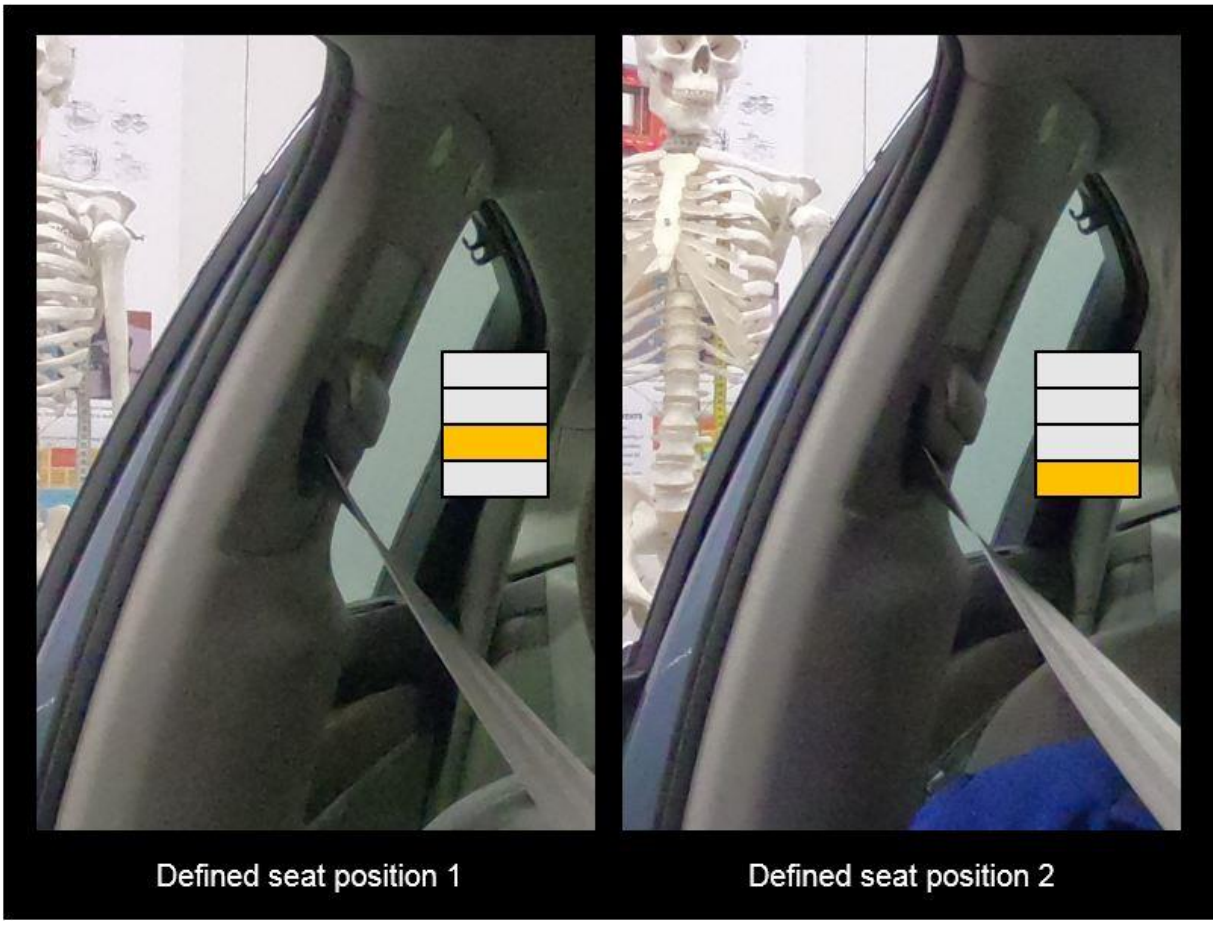


Figure 3.11 – Picture illustrating the adjusted shoulder belt height in the defined position 1 and 2. (The car had 4 adjustable levels).

It was decided to use the defined seat position 1 for all participants in the comparative user study. This was decided because of that the number of participants would be relatively low compared to the other user study. However, in the user study at the exhibition, it was decided to use both the defined seat position 1 and 2. This was the case since the goal was to have 60 visitors participating in the user study. The decision was made to use the defined seat position 1 for the first 30 participants and use the defined seat position 2 for the remaining 30 participants.

Chosen seat position

To investigate how the participants, choose and prefer to sit as passengers, they needed to be able to choose a seat position that they preferred. Thus, the participants were allowed to adjust both the seat and the seat belt as they wanted. To document the participants chosen seat position, the angle of the backrest and the position of the seat in the horizontal plane was measured. The backrest angle was documented, using an inclinometer application in a Samsung galaxy S7 edge (figure 3.12). This was done for both user studies. To reset the seat to the defined position after it had been adjusted to a chosen position, the car's seat memory function was used. This was possible since the car had electric seats.

Figure 3.12 - Picture showing how the backrest angle was measured. (The smartphone was attached to the seat using Velcro tape).

3.6.4 Designing measuring tools

Photographs

To measure the posture, shoulder belt angle and distance to suprasternal notch as well as the lap belt angle from the photographs, a photo measuring tool called ImageJ (Schneider et al., 2012) was used. The measuring tool can be used for measuring angles and distances. However, because of the participants different body types and chosen seat positions, a reference value was required to be able to get the real value of the distance measurements. Thus, the seat belt width (approximately 46mm) was used as a reference value. The real distance could be calculated as described in table 3.5.

Table 3.5 - Shows how the actual distance was calculated from the photographs using the seat belt width as a reference.

Calculating distance from ImageJ	
Belt Width in picture	X
Real belt width	Y (46 mm)
Distance in picture	Z
Real distance = (Y/X)*Z (mm)	

ASIS location

Based on "3.4.2 Defining belt fit parameters", the ASIS position in relation to the upper edge of the lap belt is an important factor in judging lap belt fit. Thus, a way of physically judging the ASIS position had to be developed. Due to integrity issues, a way of measuring the ASIS position in relation to the upper edge of the seat belt, without touching the participants bodies, had to be developed. Ideation was conducted, and a number of ideas were developed that could be tested and evaluated in pilot tests. Documentation about whether or not the lap belt is placed below or above the ASIS was considered the most important before the ideation. However, if the distance could be measured, it would be preferred. For any idea to work, all subjects needed to be able to locate the ASIS point on themselves. To do this a skeleton was used to show the iliac crest on the pelvic bone and where the ASIS is located. This way the participants could touch the iliac crest and follow the bone structure until they feel the ASIS point (figure 3.13).

Figure 3.13 - Skeleton used to help the participants find the ASIS point on themselves.

To measure the distance from ASIS to the upper edge of the lap belt three main ideas were developed through ideation. The first idea was to fold a paper around the belt and then use a marker to mark the ASIS point. The idea was to then use this paper to measure the distance. The second idea was to attach a sticker on the participants and then measure the distance from the sticker to the upper edge of the lap belt. The third idea was to allow the participant themselves point out their ASIS point with their index finger and use that as a reference when measuring the distance. All three ideas can be seen in figure 3.14.

Figure 3.14 - Picture illustrating the three ideas on how to measure the ASIS location in relation to the seat belt. Folded paper, sticker and pointing finger.

Seat belt slack

Through ideation a way of measuring the seat belt slack was developed. The idea was to attach a sticker to the seat belt close to the outlet of the seat belt and then ask the participants to tighten the seat belt as hard as they could. When the seat belt was tightened, an additional sticker was attached to the seat belt on the same spot. The seat belt was then pulled out of the outlet and the distance between the stickers could be measured (figure 3.15).


Figure 3.15 - Picture illustrating how the seat belt slack was measured after the two stickers was placed on the seat belt.

Posture

Since a kyphotic spinal curve is common among elderly, referring to "2.1.2 Changes in posture", documenting the posture of the participants was needed to be able to investigate if there were any correlations between this and the participants seat belt fit. Quek et al. (2012), used ImageJ (Schneider, Rasband, & Eliceiri, 2012), to measure lateral-view photographs of subjects and found thoracic kyphosis associated with a forward head posture. Thus, to document the posture of the participants in the user studies, a side-view photograph of the participants was taken. To assess the posture among the participants, the photo measuring tool ImageJ was used to measure the forward head position in these photographs. The tool was used to measure the craniovertebral angle (CVA) as described by Quek et al. (2012). Figure 3.16 describe how this angle was measured.

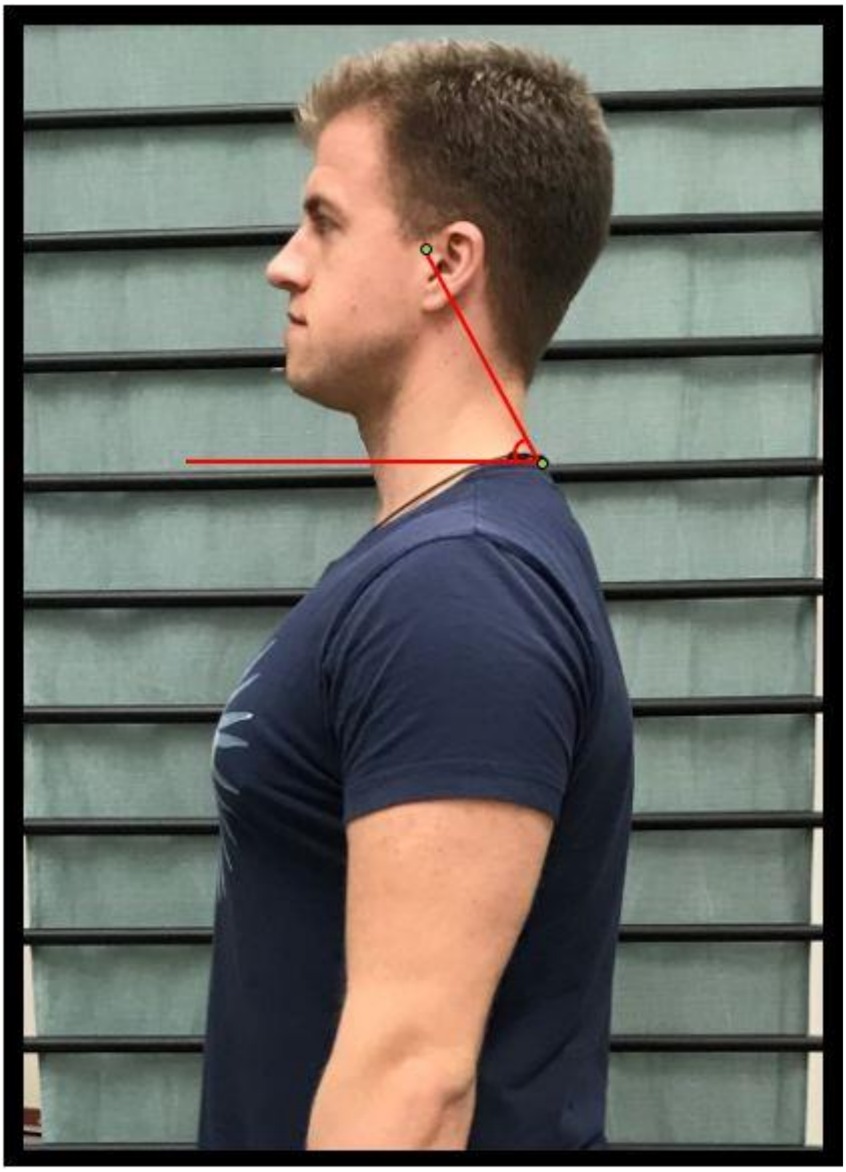


Figure 3.16 - Picture showing how the CVA was measured in the side-view photograph, using ImageJ.

3.6.5 Structuring interviews

To structure the interviews, Google form was used. The focus when formulating the questions for the structured interviews was that the interviews should touch upon the most important areas and fit into a procedure for the user studies. The interviews couldn't take too much time of the procedure of which the time limit was set to approximately 30 minutes for the comparative user study and 10 minutes for the user study at the exhibition. This made formulating the questions in a logical way important which resulted in several iterations. The areas of which the questions should touch upon was decided to be; discomfort, perceived belt fit, accessory use, and previous experiences as passenger. To include these areas in the interviews, different types of questions were asked. Thus, the interviews included both opening questions and in-depth questions. The interviews were also complemented with subjective scales for evaluating discomfort among the participants. These scales had a range from 1-10, were 1 meant no discomfort at all and 10 meant so much discomfort that you wanted to take off the seat belt and exit the car.

3.6.6 Structuring observations

Based on the factors defined in "3.4.2 Defining belt fit parameters", it was decided to use several GoPro cameras for observing and documenting the seat belt fit of the participants. One camera was placed inside the car. This camera was attached in the front window of the car using a suction mount and was used for photographing the participant from the front. Another camera was attached to a camera stance and placed on a designated position outside of the car (figure 3.17). This camera was used for photographing the participants from the side. Lastly one camera was used for taking a photograph of the participants from the side while standing outside of the car. The reasons for using several cameras were to always take each photograph in the same position for all participants and for efficiency.

Figure 3.17 - The picture shows the camera angles used inside and outside the test car. (Tape was used to mark the position of the camera tripod).

3.6.7 Equipment

The equipment used to measure and document all data from the user studies can be seen in the list below. Objective measurements in photos was made using the photo measuring software ImageJ. Documentation of physical measurements and answers from the subjective parts of the structured interview was done in Google forms. Some of the equipment used can be seen in figure 3.18.

List of equipment used:

Electronic equipment

- 2x GoPro hero 6 (Used to capture belt fit while seated in car)
- Suction cup mount for Go Pros
- Camera stand with GoPro mount
- IPad Pro (Used for structured interview, documentation of physical measurements and photo capturing outside the car)
- Inclinometer application (Samsung Galaxy S7 edge).
- ImageJ tool (Photo measuring software)

Measuring tools

- Tape measure
- Yardstick
- Bathroom scale
- Stickers (Used to mark shoulder belt to measure seat belt slack

Figure 3.18 - Picture showing some of the measuring tools used during the user studies.

3.6.8 Procedure development

Before pilot testing, a plan for the procedure of the user studies was constructed. To collect the objective and subjective data of all participants, body related data had to be measured, photographing had to be performed while seated in the car and the structured interview had to be conducted. A procedure was developed with these three steps in mind. A step-by-step description of the procedure used in the pilot tests can be seen below. The procedure was planned to take approximately 30 minutes in total:

1. Explain the scope of the project and ask participants to sign consent.
2. Gather body related data of the participant; gender, stature, weight, waist and hip circumference.

3. Ask the participant to put a sticker with their number on their chest.
4. Explain how to locate ASIS, using a skeleton model as support.
5. Photograph the participant from the side standing outside of the car and ask initial questions about how they usually travel by car.
6. Ask participant to enter the passenger seat of the car as if they were about to travel in real traffic without making any adjustments to the seat.
7. Photograph the participant from the front and side wearing the seatbelt in the defined seat position.
8. Give the participant the opportunity to adjust the seat and seat belt to fit their preference as if they were going to travel.
9. Photograph the participant from the front, side and from the side view while being seated in their chosen sitting position.
10. Close the passenger door.
11. Ask questions about if they experience any discomfort in their chosen sitting position.
12. Ask how they perceive the belt fit from a safety perspective.
13. Measure the participants chosen horizontal placement of the seat and their chosen backrest angle.
14. Measure the ASIS position in relation to the upper edge of the lap belt.
15. Finish the last questions of the structured interview.

3.6.9 Pilot testing

There are several reasons for conducting a pilot test. One of the advantages is that it can give an advance warning of where the main test of the study might fail, where research protocols is not followed or whether the instruments are inappropriate or to complicated (Teijlingen & Hundley, 2002).

In this project pilot tests were used to test and develop the adequacy of the structured interviews and find the correct camera angles to capture belt fit prior to the main user studies. Pilot tests were also used to test the developed ideas of how to measure belt slack, distance from the ASIS point to the belt, body measurements, as well as how much time that was required for the whole procedure. To develop the structured interviews some of the procedures described by Teijlingen and Hundley (2002) were used. These were; asking the subjects for feedback to identify ambiguous and difficult questions, record the time to complete the whole process of the user studies and decide whether it was reasonable, reword questions that was not answered as expected and discard all unnecessary, difficult, or ambiguous questions.

Pilot tests were first conducted for the user studies in the comparative study. This was the case since this user study was planned to be conducted before the user study at the exhibition. Doing so, it was possible to achieve an understanding of the time needed for each participant. At the exhibition, the goal was to get 60 participants. This meant less time available for each participant. Thus, pilot testing the comparative study, gave an understanding of what was possible to measure and how many questions that were possible to ask, in a specific time frame. The idea was to, based on the outcome of the pilot testing of the comparative study and the implementation, refine the procedure and the structured interview to fit the user studies during the exhibition.

Regarding camera angles, several possible setups/angles inside and outside the car was tested (figure 3.19). The photographs were printed and discussed in a meeting with the supervisor to get the best possible setup to capture belt fit during the user studies. After pilot testing the structured interviews for the comparative user studies, input from the pilot participants were discussed with the outsourcer. Furthermore, since the user studies included gathering different measurements such as distance from belt to ASIS point and belt slack, the outcome of the pilot tests were discussed with the outsourcer.

Figure 3.19 - Pictures taken during pilot testing to test camera angles.

3.6.10 Finalizing user studies

After everything was pilot tested, the structured interviews, structured observations, measuring techniques and the procedure were updated based on flaws found during the pilot tests.

Structured observations

After pilot testing the whole procedure of the user studies it became apparent that it was hard to remember to take all photographs. Thus, the decision was made to include check-boxes in the interview documents in Google form. This to reduce the risk of missing any of the steps during the user studies. During the pilot tests it was also found that the arms of the participants made it hard to observe how the lap belt was positioned. It was also hard to measure the lap belt angle in the photographs. Thus, the decision was made to add an extra photo from the side view, in the chosen seat position, where the participants were asked to grab the top side handle inside the car. This made it easier to observe the lap belt fit in the photographs (figure 3.19 above).

Structured interviews

The questions for the interviews were reformulated and structured in a manner that suited and followed the finalized procedure of the user studies, as well as facilitated analyzing the results. This resulted in that initial questions were asked outside of the car when documenting the body data of the participants. The majority of the questions were then asked while being seated inside the car and adapted after the procedure of the user studies. Three separate documents were created in Google form; one for the user study at the exhibition and two for the comparative user study (old and young). The structured interviews at the exhibition differed from the structured interviews in the comparative study, regarding the number of questions asked. Less questions were asked during the interviews at the exhibition. This was the case because of the aim and environment of the user study at the exhibition. The documents with the questions that was used for the structured interviews at the exhibition and in the comparative user study can be found in Appendix 4 & 5.

Measuring ASIS location

The three ideas for measuring the ASIS distance to upper edge of the lap belt were tested in a pilot test. The pilot test displayed problems with the first two ideas. It was hard to make the folded paper idea to work efficiently. The sticker idea did not work efficiently either, since the clothes made the sticker move around. The third idea where the participants were allowed to point out the ASIS point themselves was found most effective and was therefore chosen.

3.7 Implementing user studies

When everything was updated the user studies were conducted. This section of the report describes the final procedure for the user studies and how each study was carried out.

3.7.1 Procedure of user studies

The final procedure that was used for both the comparative user study and for the user study at the exhibition, consisted of eleven steps (figure 3.20).

Figure 3.20 - Illustration of all steps taken during the final procedure for the user studies.

3.7.2 Comparative user study

The comparative user study included both elderly and young participants. The study with elderly participants was conducted during several days, based on when the elderly could participate. The young participants were recruited randomly at Lindholmen after all elderly participants had participated. In total the comparative user study resulted in 11 elderly and 11 young participants. The final layout, where the comparative user study was carried out, can be seen in figure 3.21 and 3.22. The eleven-step procedure, as described in “3.5.1 Procedure of user studies”, was followed for both the young and elderly participants. The seat position used for the comparative user study was the defined seat position 1. All participants were rewarded with a gift voucher or movie tickets for participating in the study. The rewards were given to the participants after they had participated.

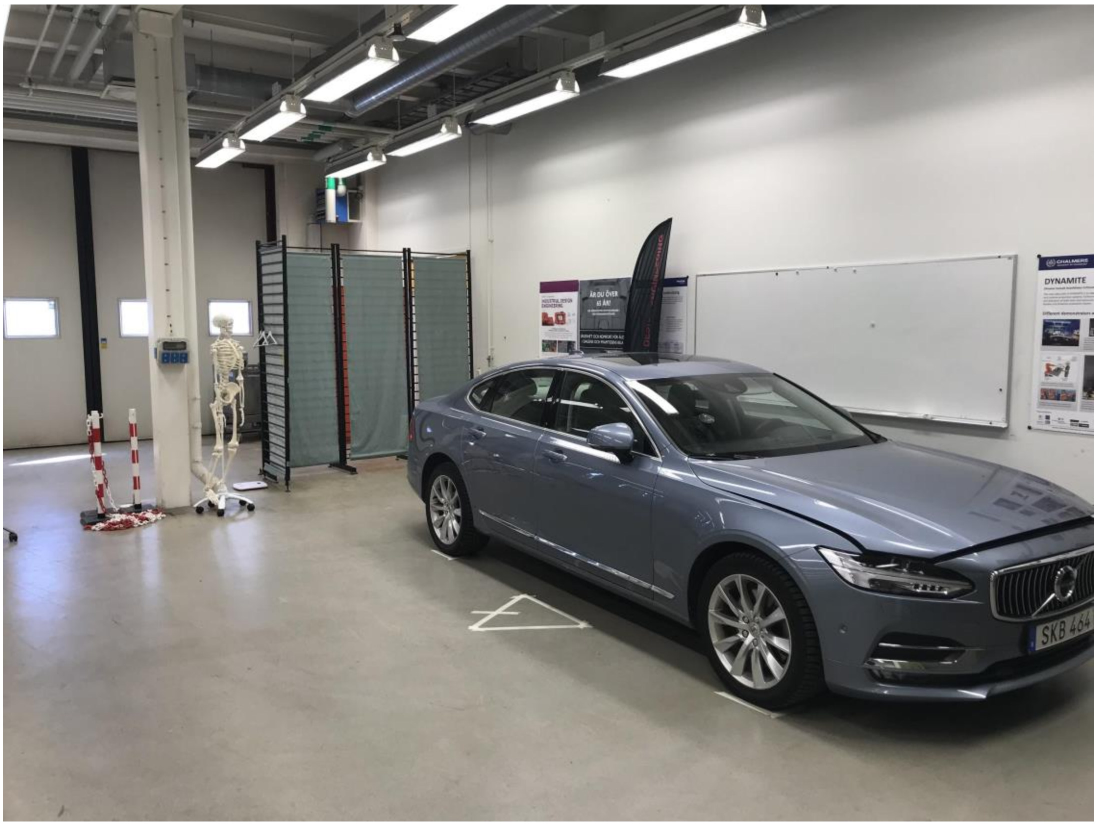


Figure 3.21 - Picture of the layout where the comparative user study took place.

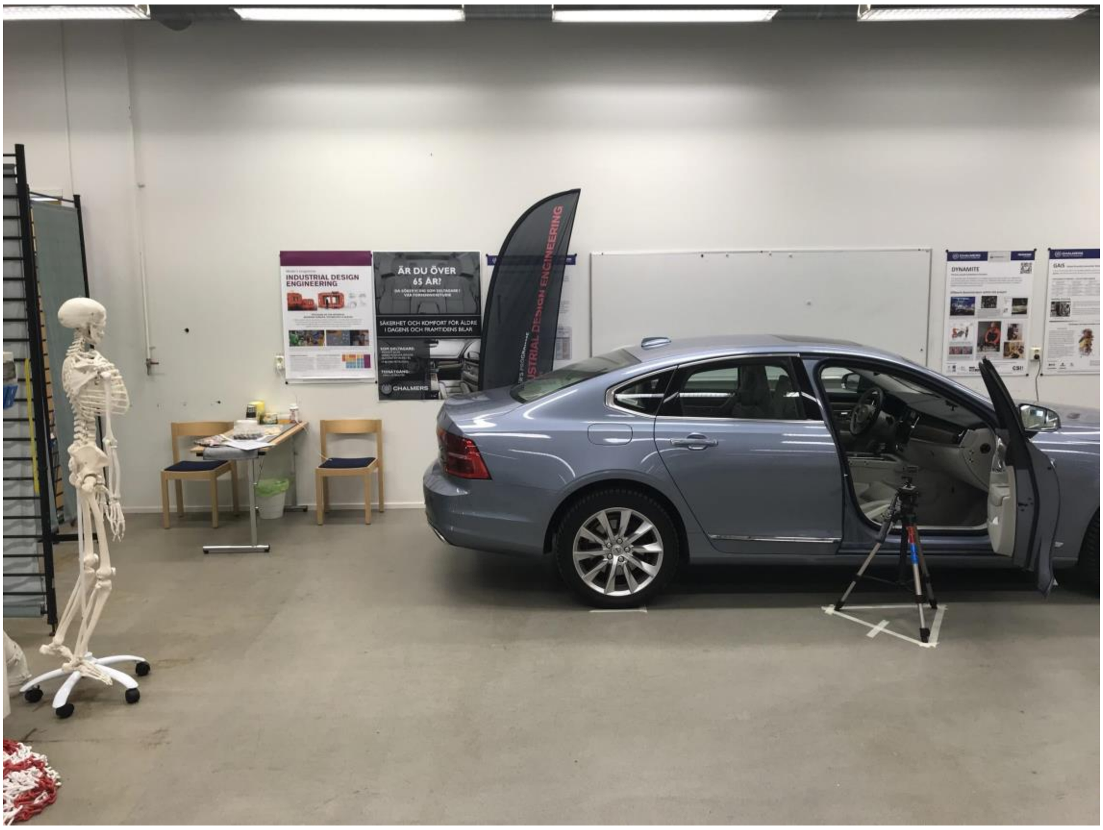


Figure 3.22 - Picture of the layout where the comparative user study took place.

An example of the data collected of an elderly participant in the comparative user study can be seen in table 3.6 and 3.7. All photographs taken of the same participant can be seen in figure 3.23.

Table 3.6 - Example of body data collected during the comparative user study.

Body data
Participant number: 9
Gender: Female
Age: 77 years old
Stature: 170 cm
Weight: 85 kg
Waist circumference: 100 cm
Hip circumference: 105 cm

Table 3.7 - Example of data collected during the comparative user study.

Subjective and objective data
Travel as: Driver
Car travel frequency:2-3 days per week
Do not experience any discomfort while being seated in the car during the user study
Chosen backrest angle: 18 degrees
Chosen horizontal placement of car seat: 12 cm
Perceive the seat belt fit as safe in the position it is in the chosen seat position
Asis location: 10 mm above the upper edge of the lap belt
Slack: 25 mm
Usually adjust the angle of the backrest in cars to be able to look out of the front window and “participate in the traffic”

Do not usually use any accessories to improve comfort or avoid discomfort
Do not usually experience any discomfort as a passenger in cars

Figure 3.23 - Example of all pictures taken of a participant during the comparative user study.

3.7.3 User study at exhibition

The user study at the exhibition was carried out for three days. The exhibition was aimed at seniors and took place at Svenska Mässan in Gothenburg. The exhibition usually has around 8000 visitors in total and take place for three days, from 10 am. to 4 pm each day. Thus, the goal of achieving 60 participants would be possible. To attract visitors to participate, the car, posters and snack table were placed in a specific way in the booth (figure 3.24). The posters were placed in a way that made them visible from different angles. The car was placed with the front end pointing out, to make it easy to both perform the user study and to make the whole booth look attractive. Lastly, the snack table with cookies and the information sheets was placed next to the car. Visitors that passed by the booth at the exhibition were randomly recruited for the study if they met the criteria of being over 65 years old. The user study followed the eleven-step procedure, as described in “3.5.1 Procedure of user studies” and each test took around ten minutes.

In total, the user study at the exhibition resulted in that 55 elderly visitors were recruited as participants. The defined seat position 1 was used for the first 32 participants. The idea was then to use the defined seat position 2 for an equal number of participants. However, data on three participants could not be used for analyzing the shoulder belt fit in the defined seat position 2. This was the case since the shoulder belt was height adjusted to the wrong level for these. Furthermore, due to the remaining time available during the exhibition it was only possible to achieve 20 participants using the defined seat position 2. This however, did only reduce the number of participants that could be analyzed on shoulder belt fit in the defined seat position 2. All 55 participants could be analyzed on lap belt fit in both the defined seat position 1 and 2 as well as on all aspects in the chosen seat position.

Figure 3.24 - Picture of the booth at the user study at the exhibition.

An example of the data collected of a participant in the user study at the exhibition can be seen in table 3.8 and 3.9. All photographs taken of the same participant can be seen in figure 3.25.

Table 3.8 - Example of body data collected during the user study at the exhibition.

Body data
Participant number: M28
Gender: Male
Age: 75 years old
Stature: 183 cm
Weight: 120 kg

Waist circumference: 134 cm
Hip circumference: 129 cm

Table 3.9 - Example of data collected during the user study at the exhibition.

Subjective and objective data
Travel as: Driver
Car travel frequency:2-3 days per week
Do not experience any discomfort while being seated in the car during the user study
Defined seat position 2 (shoulder belt adjusted to the lowest level)
Chosen backrest angle: 23 degrees
Chosen horizontal placement of car seat: 12 cm
Perceive the seat belt fit as safe in the position it is now
Asis location: 55 mm above the upper edge of the lap belt
Slack: 45 mm
Do not usually use any accessories to improve comfort or avoid discomfort
Usually experience discomfort in the whole body as a passenger in certain car brands because of their construction

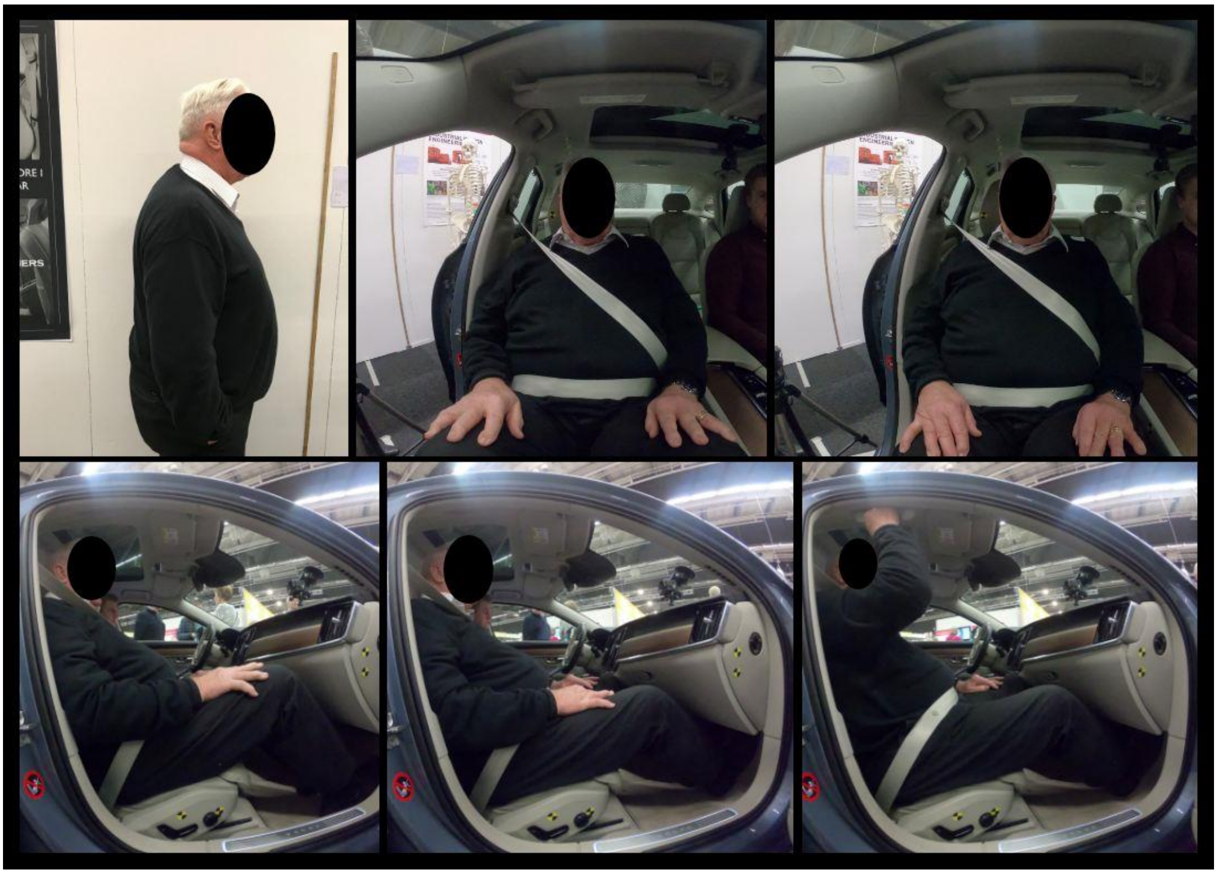


Figure 3.25 - Example of all pictures taken of a participant during the user study at the exhibition.

3.8 Data compilation and analysis

The data retrieved from the comparative user study and the user study at the exhibition was automatically compiled into Excel through Google form. However, to facilitate further analysis, all data was placed into three separate excel documents; One for the data from the exhibition, one for the data from the elderly and one for the younger participants in the comparative study. Once the data was compiled into these three Excel documents, the analysis was conducted.

The analysis included analyzing the photographs, the participants subjective answers and the physically measured data. The analysis of the data from the comparative user study differed from the analysis of the data from the user study at the exhibition, regarding the aim of each user study. The main focus when analyzing the data from the user study at the exhibition was to find out what factors affected seat belt fit among elderly. The main focus when analyzing the data from the comparative user study was to find differences between the elderly and the young participants. However, since the objective data was collected in the same manner for both user studies, the data from the exhibition could in some cases be used in comparison to support trends found in the comparative study.

The analysis consisted of three steps. The first step was to analyze the photographs. This was done for both the defined seat positions and for the chosen seat positions. The main focus when analyzing these was the seat belt fit. This was done by observing and judging how the seat belt´s two parts; the lap and shoulder belt was positioned on the participant. The analysis was based on "3.4.2 Defining belt fit parameters". To measure the lap belt angle, distance from suprasternal notch to the upper edge of the shoulder belt and the shoulder belt angle, the photo measuring tool ImageJ was used. The second step was then to analyze the seat belt fit in relation to the body data and measurements. This was done in order to find out what affected the seat belt fit among the elderly participants and what differed the young from the old participants. Since photographs were taken of the participants in the defined seat position 1 and 2, it was possible to analyze what age and body measurement related factors that influenced the seat belt fit. Furthermore, it was possible to analyze the profile standing photo to investigate how the shoulder belt fit was affected by the posture of the participants. The third step was to analyze the participants subjective answers in relation to their chosen seat position. Doing so it was possible to find out the participants awareness of their seat belt fit from a safety perspective and to find out how they preferred to sit as passengers.

To illustrate the findings and to find trends, different types of graph-based diagrams were used. The main diagrams used were histograms, pie charts and scatter plots. Different bin widths were used for the histograms to further analyze trends. Furthermore, to show data trends, linear trendlines were added in the scatter plots to facilitate analysis. This was done in Microsoft Excel, where it is possible to add trendlines to show data trends in 2-D charts such as scatters or columns.

3.9 Creation of design guidelines

Based on the findings from the user studies and the investigated theory, design guidelines could be developed. When developing the design guidelines, the idea was to create guidelines which could be used for all occupant restraint systems and passenger seats. This with the assumption that all occupant restraints system will be designed to be placed on the occupant's body with the purpose of catching the bony structure during a crash and the passenger seat is faced forward relative to the direction the car is moving. The idea was the same for all factors used for developing design guidelines. The design guidelines were not developed to fit a specific car model, rather so that they could be used in different scenarios when aiming to include elderly as passengers in cars.

Results

The results consist of four chapters which presents the findings from the two user studies.

4. The elderly passenger

In this chapter the result from the 55 older participants in the structured interview at the exhibition is presented. It includes participant population, discomfort in test car, previous experienced discomfort, accessory use, posture, adjustments normally used by the participants, and chosen sitting position.

4.1 Participant population

Out of the 55 participants, 42% were females and 58% were males. The average stature was 181 cm for males and 167 cm for females. The average BMI was approximately 25 for males and 26 for females. A comparison between the participant population with the average of 70-79-year old's in Sweden can be seen in table 4.1. When comparing the statistics from Statistics Sweden (SCB, 2010) the participants stature and weight was slightly over average. The average BMI among females was within the error margin and for males slightly lower. The demographics of all participants from the exhibition study can be seen in appendix 6. A quick overview of the participants can be seen in figure 4.1.

Table 4.1 - Table showing a comparison between body data from Statistics Sweden and the participants in the user study at the exhibition.

Statistics Sweden (SCB) 2010						
70-79 years	Stature		Weight		BMI	
Male	176,6	± 0,4	81,4	± 0,8	26,1	± 0,2
Female	163,8	± 0,4	68,9	± 0,8	25,7	± 0,3
Average among participants (32 males, 23 females)						
Male	181,1		83,0		25,3	
Female	167,1		71,2		25,6	

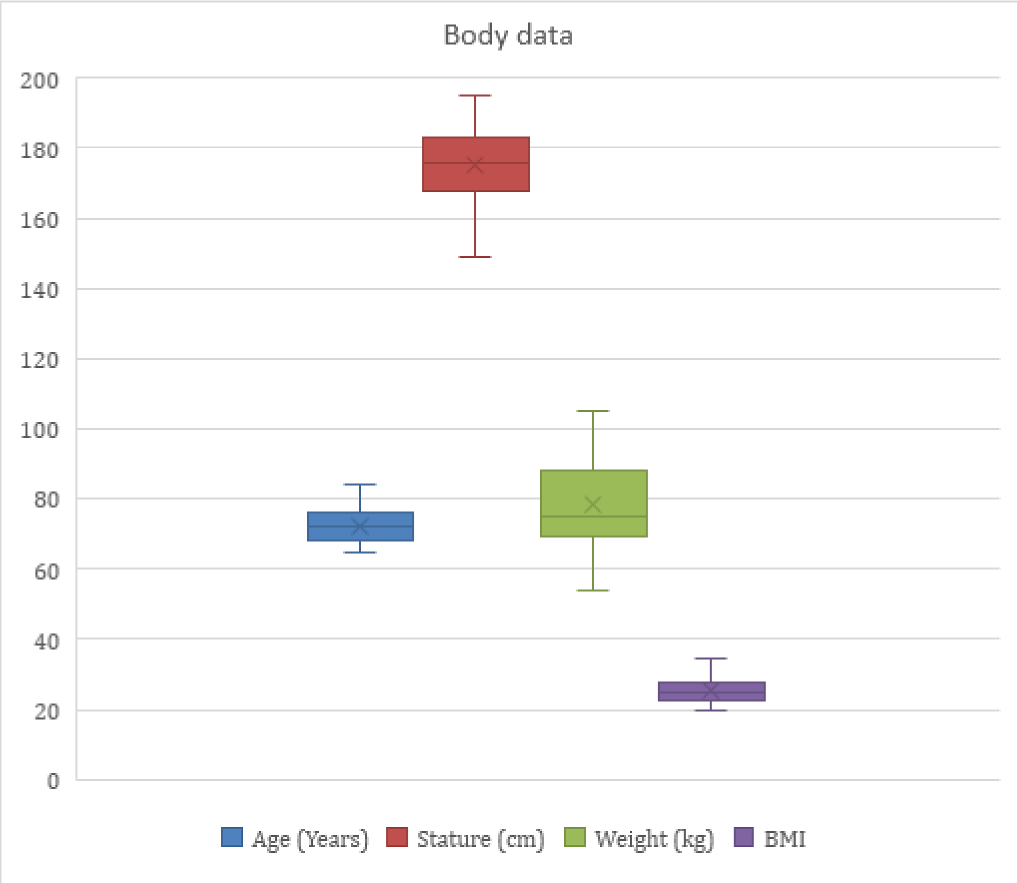
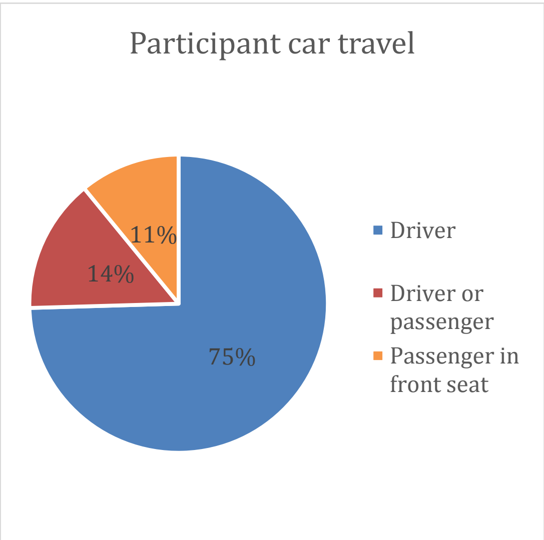


Figure 4.1 - Box plotted overview of the participant population at the user study at the exhibition.

4.1.1 Car travel experience among the participants

42% (23) female and 58% (32) male subjects participated in the study. 75% (41) of the participants said they are usually traveling as drivers, 14% (8) equally as much as driver or passenger and the remaining 11% (6) normally travel as passengers (figure 4.2). Regarding car travel frequency 98% (54) travel by car weekly. 33% (18) of all participants travel 4-6 days/week, 31% (17) every day and 23% (13) 2-3 days/week (figure 4.3).



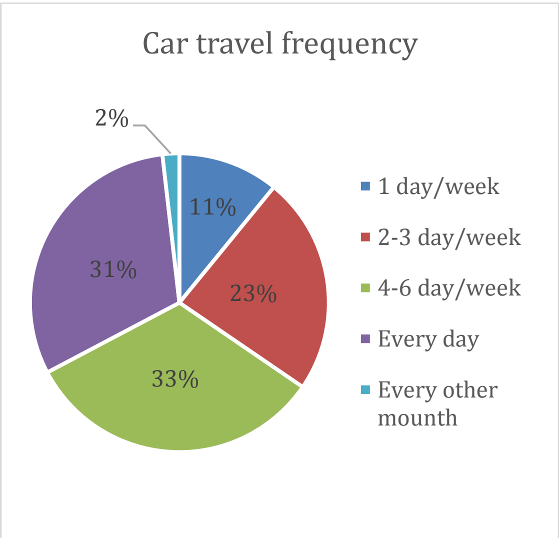


Figure 4.2 and 4.3 - Showing in what seat the participants usually travel and how often they travel by car.

4.2 Seat and seat belt discomfort in test car

During the static testing in the passenger seat of the Volvo s90 car at the exhibition, 80% (44) experienced no discomfort in their chosen position (figure 4.4). Out of the 55 participants, 20% (6 females and 5 males) experienced some sort of discomfort whereas 5% (3) experienced more than one discomfort. The result from the subjective scale which shows the intensity of the discomfort perceived on a scale from 1-10 showed an average of 4 out of 10, where 8 was the highest and 2 the lowest. When asking the question where on their bodies they felt discomfort none occurred more than the others. However, among the 11 participants that experienced discomfort, the discomfort was perceived in the lower back, back thigh, bottom, and neck/head in their chosen sitting position. When asking what in the seat that contributed to the discomfort the seat cushion, backrest and headrest was mentioned. Regarding the seat cushion they experienced it as too stiff and commented that they felt discomfort due to the edges between the different parts of the seat cushion. In the backrest there was a lack of lumbar support mentioned. Regarding the headrest they perceived it as too high since they could only rest the back head on it with no neck support. None of the participants mentioned the seat belt.

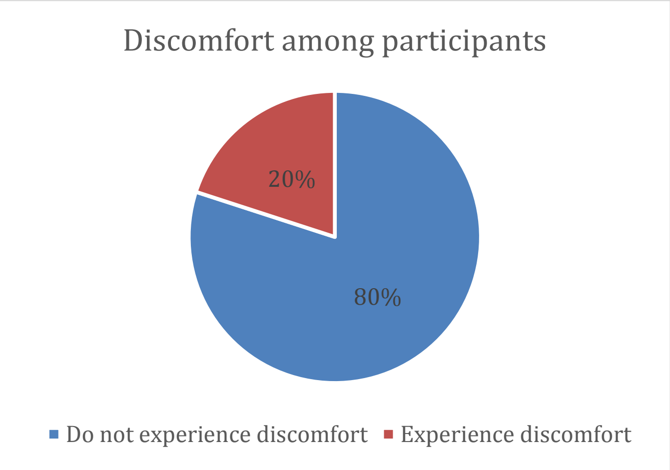


Figure 4.4 – Showing, in percentage, how many of the participants experienced discomfort in the test car.

4.3 Previous experience of discomfort

When asking the question if the subjects have experienced discomfort in their own or anyone else's car that they often travel in, 57% (35) could not recall any discomfort. However, 43% (10 males and 10 females) mentioned problems with discomfort. Out of these, 7 mentioned previous problems with discomfort in the lower back due to the lack of lumbar support. Additionally, 7 mentioned previous discomfort in the back thigh or bottom due to the seat cushion. Four had experienced discomfort in legs and knees due to the length or height of the seat cushion. Two of the subjects mentioned discomfort in the neck due to the neck rest.

When asking the question if they have had any experience of discomfort caused by the seat belt 67% (37) said no and 33% (18) mentioned that they have had problems with discomfort caused by the seat belt (figure 4.5). The most common discomfort (24%, 13 out of 18) was the belt being in contact with the neck. According to the result females may be more likely to experience discomfort due to the belt being in contact with the neck since 11 out of the 13 were female.

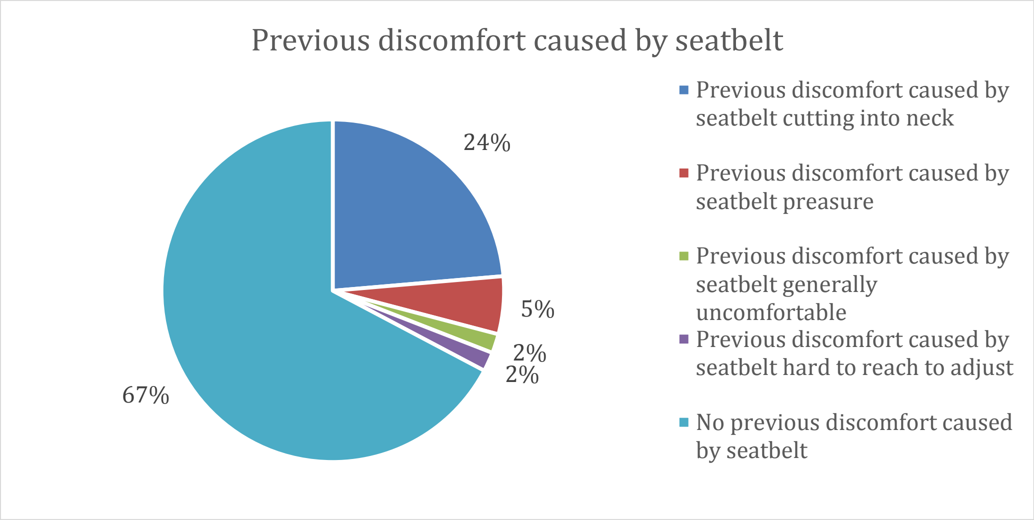


Figure 4.5 – Showing, in percentage, how many who previously in other cars have experienced discomfort caused by the seat belt and why.

4.4 Accessory use

When asking the participants at the exhibition if they have or are using any add-on accessories in their own cars to improve comfort, 84% (46) did not use any accessories (figure 4.6). 16% (9) said they have used some sort of add on accessories to improve comfort. Four out of these 9 used an extra cushion to sit on to make the seat softer or to increase the sitting height. Two used a pillow for better neck support and 2 used a pillow behind the lower back to improve the lumbar support.

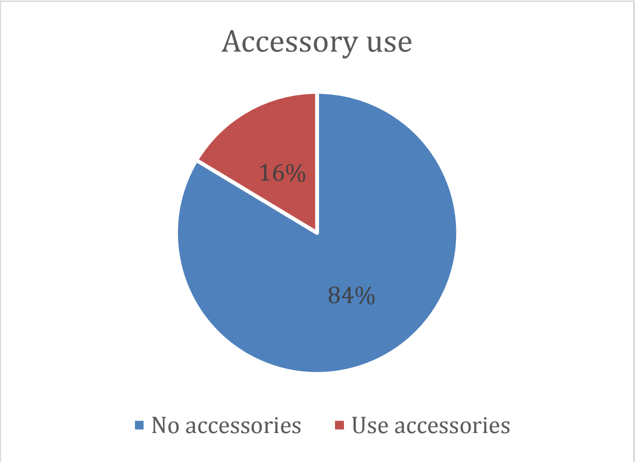


Figure 4.6 – Showing, in percentage, how many of the participants who have used accessories in their own cars.

4.5 Posture

During the user studies the standing posture of the participants was captured through a profile photo. These photographs were then used for measuring the craniovertebral angle (CVA) of each participant. An example of a measured CVA of a participant can be seen in figure 4.7. A lesser angle indicates according to Quek et al. (2012), a more forward head posture which is associated with thoracic kyphosis.

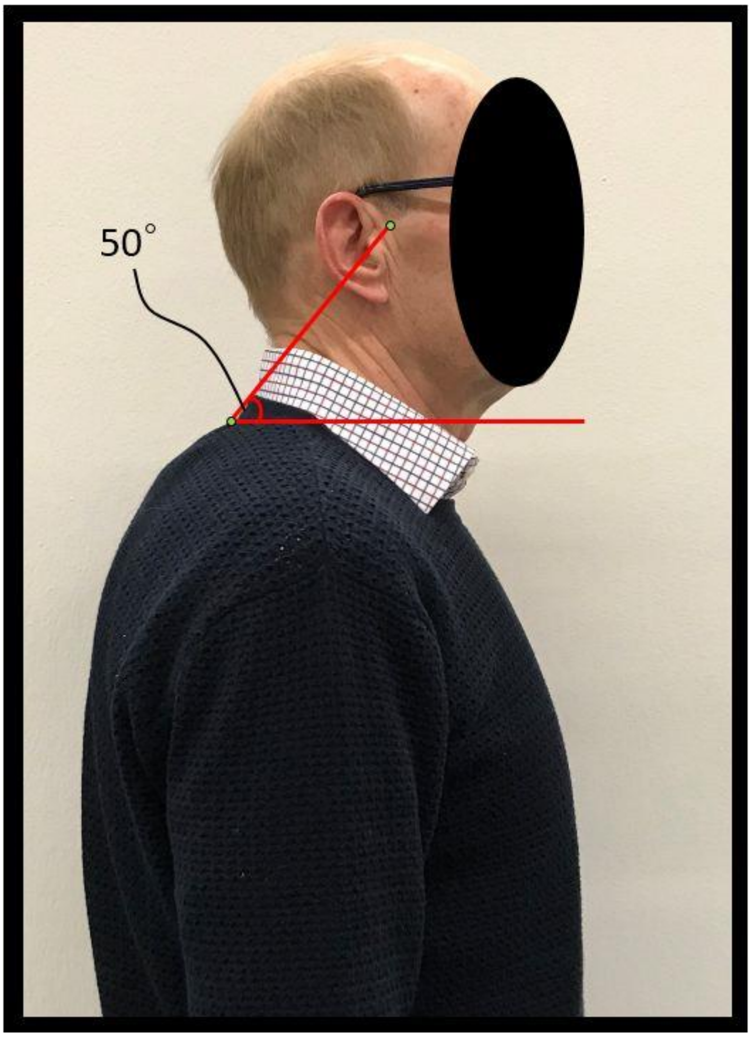


Figure 4.7 - Example of a CVA measurement on one of the participants.

The CVA was found in average lower among the male participants compared to the female (males: 49 degrees, females: 54 degrees). The distribution of the craniovertebral angles for both genders compared to age among the 55 participants can be seen in figure 4.8. A trend of the CVA decreasing with increasing age was found for the male participants. This was however, not the case among the female participants.

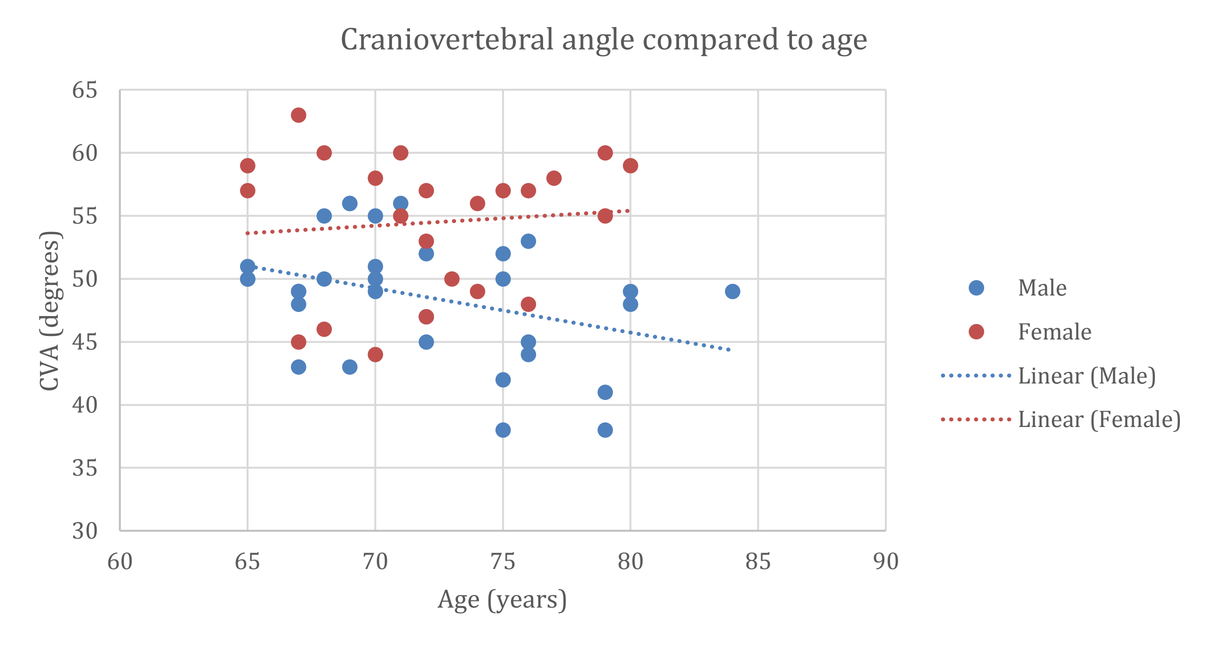


Figure 4.8 - CVA compared to age among males and females.

4.6 Chosen sitting position

In this section the result on how the participants choose to adjust their seat at the exhibition is presented in terms of backrest angle, horizontal seat position and adjusted seat height.

4.6.1 Chosen backrest angle

At the exhibition when the participants were asked to adjust the seat as they wanted 56% (31) chose an angle between 22 and 24 degrees which is close to the backrest angle in the defined seat positions (22 degrees). 17% (9) chose a more reclined backrest angle and 27% (15) chose a more upright sitting position (figure 4.9).

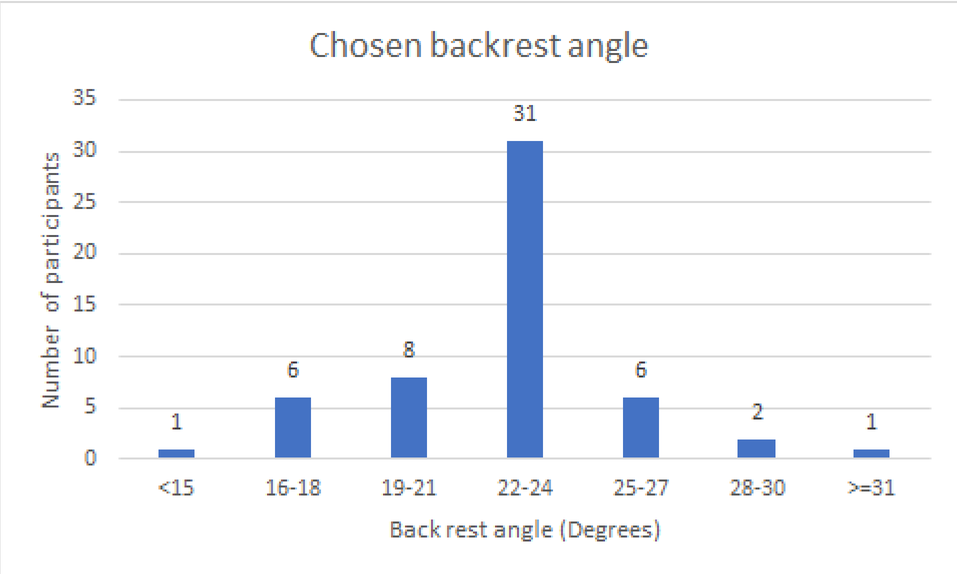


Figure 4.9 - The distribution of chosen backrest angles among the participants.

4.6.2 Chosen horizontal seat position

From the defined seat position, 51% adjusted the seat in the horizontal plane. Fifteen adjusted the seat forward and 12 backwards. However, 6 adjusted the seat noticeable (More than 5cm) forward and 7 backwards. The result shows no trend that moving the seat forward or backward are more preferred among the elderly participants at the exhibition (figure 4.10).

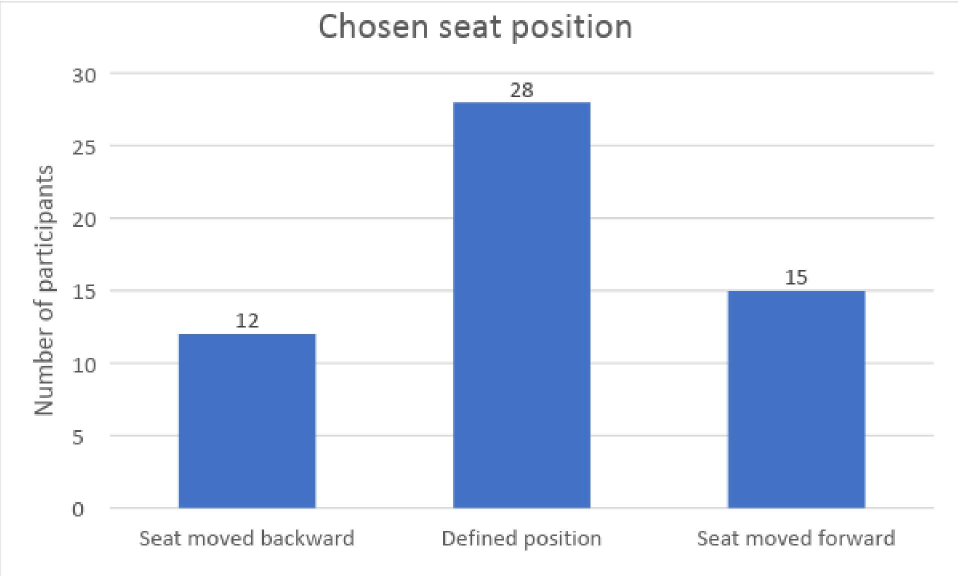


Figure 4.10 - Showing how many of the participants who, in the chosen position, moved the seat forward or backward relative to the defined position.

4.6.3 Seat height adjusted in chosen position

At the exhibition 20 out of 55 participants increased the seat height noticeable (12 female and 8 male) in the chosen sitting position based on observation from the side view photos taken

4.7 Summary of results: The elderly passenger

The results are based on the exhibition population only. The result should be treated as an example of who the elderly car traveler might be and what sort of discomfort they might experience.

- The participants were most often drivers.
- The participants travel by car several days a week.
- 20% experienced discomfort in the test car.
- Regardless if asked about the test car or other cars they often travel in, the participants complain about discomfort in the lower back, back thigh (and bottom), and neck/head
- The participants associate lower back discomfort with a lack of lumbar support, back thigh and bottom discomfort with a stiff and edgy seat base and neck/head discomfort with the height of the headrest.
- 33% have experienced discomfort due to the seat belt in other cars.
- Previous discomfort (perceived in other cars) caused by the seat belt being in contact with the neck was more common among females since 11 out of 13 were females.
- Using accessories to improve comfort was not found common among the participants.
- The male participants averaged lesser CVA than the females which indicate a more forward head posture.
- The forward head posture increase among males with increasing age but not for females.

5. Comparing young and old passengers

In this chapter the findings from the structured interviews and the analysis of the posture are shown. Whereas chapter 4 focus on the differences within a larger group of older people this chapter focuses on the differences between the older target group and the younger reference group in the comparative study. The chapter includes comparisons between car travel experience, discomfort in test car, previous experience of discomfort, accessory use, chosen seat positions and posture analysis.

5.1 Participants

The result from the comparative user study shows no noticeable difference in how the participants usually travel by car between young and old. Six out of 11 in the young reference group usually travel as passengers only, 4 as drivers and 1 as passenger in the back seat. In comparison all people in the older target group normally travel as drivers whereas 5 of them travel equally as drivers or passengers. However, regarding the car traveling frequency there is a noticeable difference between the reference group and the older group. All 11 of the older group travel by car weekly whereas 8 of them travel 4-6 times/week or more. In the young reference group 7 out of the 11 travels 1 time/week or less and 3 people 2-3 times/week and 1 travel 4-6 times/week. The demographics of the two groups, old and young, can be seen in appendix 6. According to data from Sweden Statistics (SCB, 2010) the average BMI among the old are higher among the males and lower for the females compared to the Swedish population aged 70-79 years. For the young group the average BMI is higher than average for both the male and female participants compared to 20-29-year old's in Sweden. A quick overview of the old and young participants can be seen in figure 5.1 & 5.2.

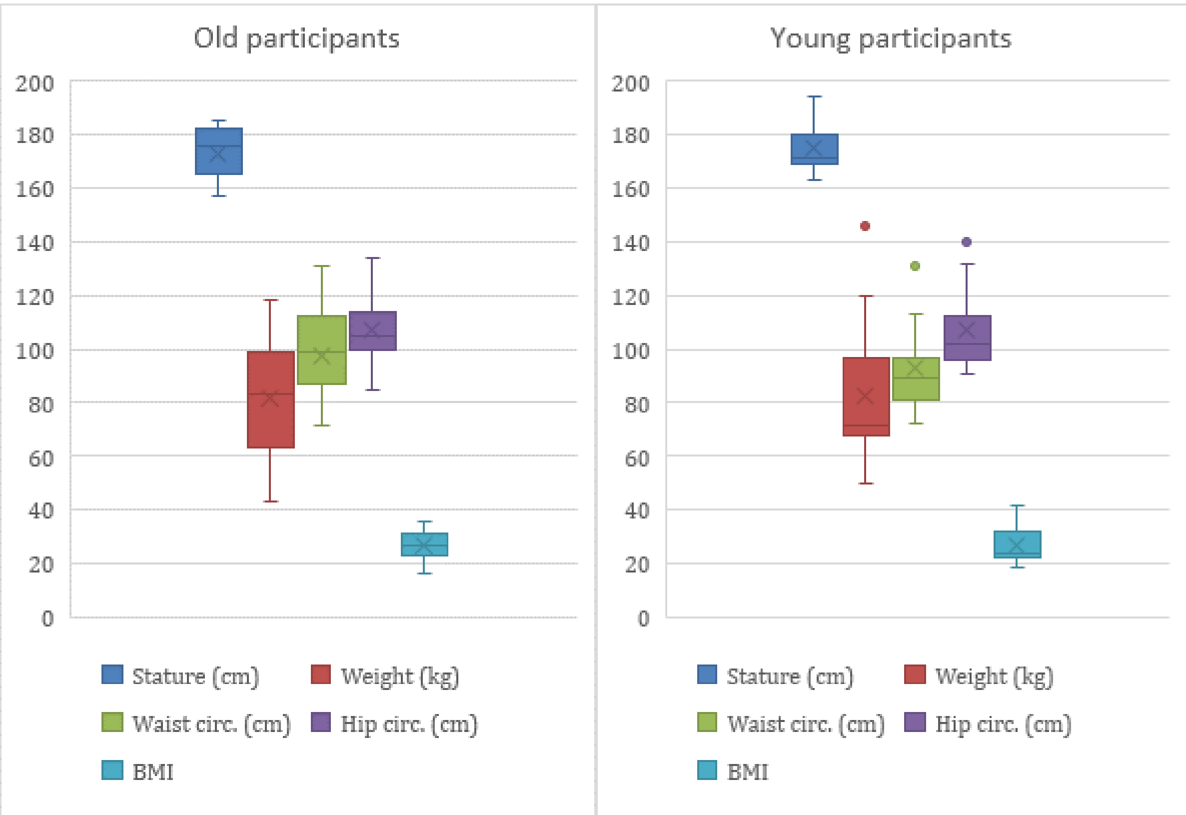


Figure 5.1 and 5.2 - Box plotted overview of the old and young participants population at the comparative user study.

5.2 Seat and seat belt discomfort in test car

When asking the participants if they felt any discomfort while seated in their chosen position during the structured interview in the car, 8 out of 11 answered that they do not experience any discomfort in both groups. The 6 participants (3 young and 3 old) who experienced discomfort rated it as 4 or 3 in the subjective evaluation scale from 1-10. However, in the younger reference group two subjects mentioned more than one discomfort compared to the older target group where none expressed more than one discomfort. When asking the question where on their bodies they felt discomfort, none occurred more noticeable than the others. In the younger group, one expressed discomfort in the lower back and on the back of the head (complaint about bad support for the back and did not like the head rest), one underneath the knee (expressed bad support under the knee) and one in the back thigh and neck (thought the seat cushion was to narrow and could not adjust the headrest). In the older target group one expressed discomfort in the neck (Could not tilt it backwards as wanted), one in the bottom (complaint that it felt like sitting in a bowl) and one in the neck (shoulder belt in contact with the neck).

5.3 Previous experience of discomfort

Since the questions about discomfort experienced in their own car or anyone else's car that they often travel in was added later in the project no comparison between young and old can be done. However, the two last subjects of the older target group and all in the younger reference group got the question. Out of the two in the older group one expressed previous experienced discomfort in the back thigh due to lack of support in the seat cushion. On the following question about discomfort caused by the seat belt none of them had any experiences. Regarding previous experiences among the younger group, 5 out 11 have had problems with discomfort in other cars. In these cases, it caused discomfort in the upper back (due to bad back rest support), in the hip and lower back (due to bad roominess), lower back (caused by lack of lumbar support) and back thigh (due to the seat cushion).

When asking the question if the younger reference group have had any experience of discomfort caused by the seat belt, 5 out of 11 mentioned problems with the belt being in contact the neck. Out of these, 3 were male and 2 female which differs compared to the result from the exhibition where a significant majority were female.

5.4 Accessory use

When asking the younger reference group if they have or are using any add-on accessories in their own cars to improve comfort, 1 out 10 have used an accessory. In this case a pillow was used to support the lower back while driving but also sometimes as passenger. Compared to the young, 3 out of 11 in the older target group said they have been using some sort of accessory. One of them normally used an extra seat pillow and an add-on lumbar support to increase the sitting height and reduce the risk of tiredness in the lower back. The remaining two only used accessories while traveling longer distances and not specifically because of discomfort.

5.5 Adjustments normally used by the participants

According to the results from the structured interview the adjustment for moving the seat forward and backward in the horizontal plane as well as the one for tilting the backrest are the most commonly used. In both the younger and the older group 10 out 11 used the adjustment for moving the seat in the horizontal plane. Regarding tilting the backrest, 8 out of 11 normally adjust the seat angle among the younger and 7 out of 11 among the elderly. One of the 11 younger normally used a third adjustment for adjusting the seat height. In comparison to the older group, 3 out of 11 normally adjusted the seat height. Additionally, two of the older normally adjusted the headrest which none of the younger mentioned. When asking the question why they adjust, they normally answered to sit comfortably. However, a difference was found between the two groups which was related to the adjustment of the seat height. In the old group, four of the participants stated achieving a good field of sight was the main reason behind why they adjusted the seat height, or the backrest angle compared to one in the young reference group. Furthermore, two of the elderly who adjusted the seat height also mentioned that it was important for them to observe and follow the traffic and red lights when somebody else drives the car.

5.6 Posture

The craniovertebral angles (CVA) were compared between the young and old participants. It was found that the average CVA was greater among the young participants (58 degrees) compared to the old participants (51 degrees). The distribution of the craniovertebral angle compared to age for both the young and old participants can be seen in figure 5.3. The result displays that the CVA is lower among the old participants compared to the young participants. This indicates that the old participants have a more forward head posture which is associated with thoracic kyphosis. When comparing the result to the CVA among the 55 elderly participants from the exhibition, the average CVA was also 51 degrees.

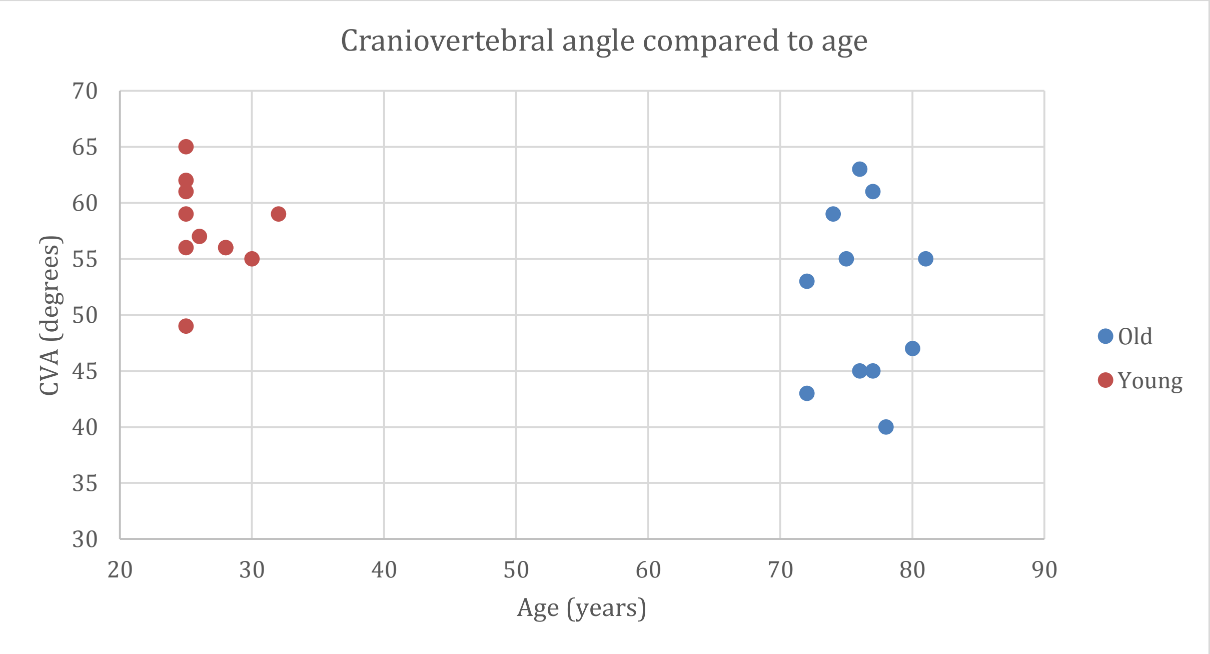


Figure 5.3 – CVA compared to age among old and young participants.

5.7 Chosen sitting position

In this section the result on how the participants choose to adjust their seat at the comparative study is presented in terms of backrest angle, horizontal seat position and adjusted seat height.

5.7.1 Chosen backrest angle

When asking the participants during the comparative study to adjust the seat as they wanted no noticeable difference was found when comparing the measured backrest angle between young and old. However, the result shows that the older group preferred the backrest to be slightly more tilted compared to the younger. Among the younger participants, 5 out of 11 chose a backrest angle near the defined seat position (22 ± 1). In comparison, 5 out of 11 in the older group chose a backrest angle near (24 ± 1) (figure 5.4).

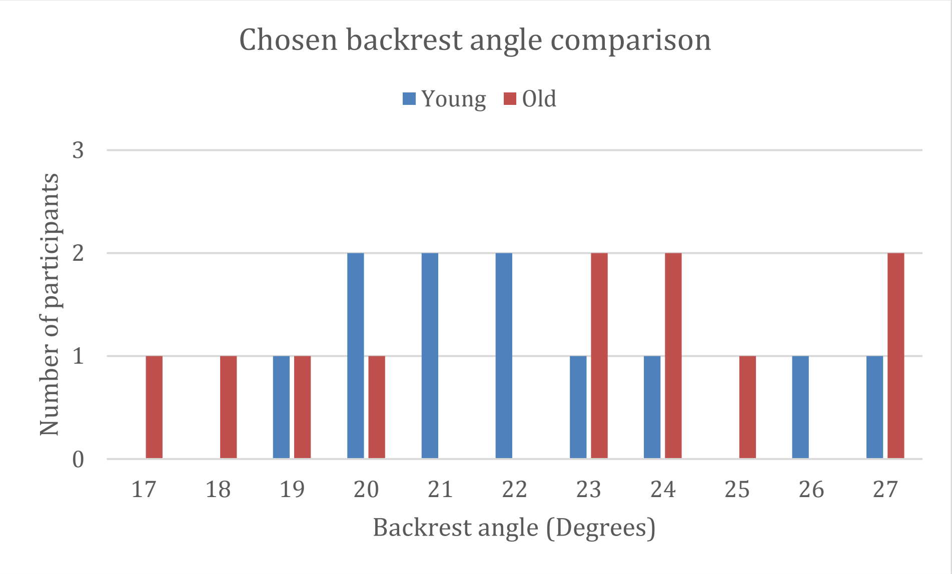


Figure 5.4 - Comparison of the measured backrest angle between old and young participants.

5.7.2 Chosen horizontal seat position

From the defined seat position, 7 out of the 11 young participants adjusted the seat in the horizontal plane. Five of the young adjusted the seat forward and 2 backwards. However, 3 adjusted the seat noticeable (More than 5cm) forward and none backwards. In comparison 4 out of the 11 old participants adjusted the seat (2 forward and 2 backwards). One adjusted the seat noticeable forward (5cm forward).

5.7.3 Seat height adjusted in chosen position

In the comparative study a trend was found regarding the chosen seat height among the older group compared to the young reference group. Six out of 11 in the older target group adjusted the seat height noticeable (3 female and 3 male) and in the younger group 1 out of 11 adjusted the seat height noticeable. In figure 5.5, an example can be seen of a participant noticeable adjust the seat height.

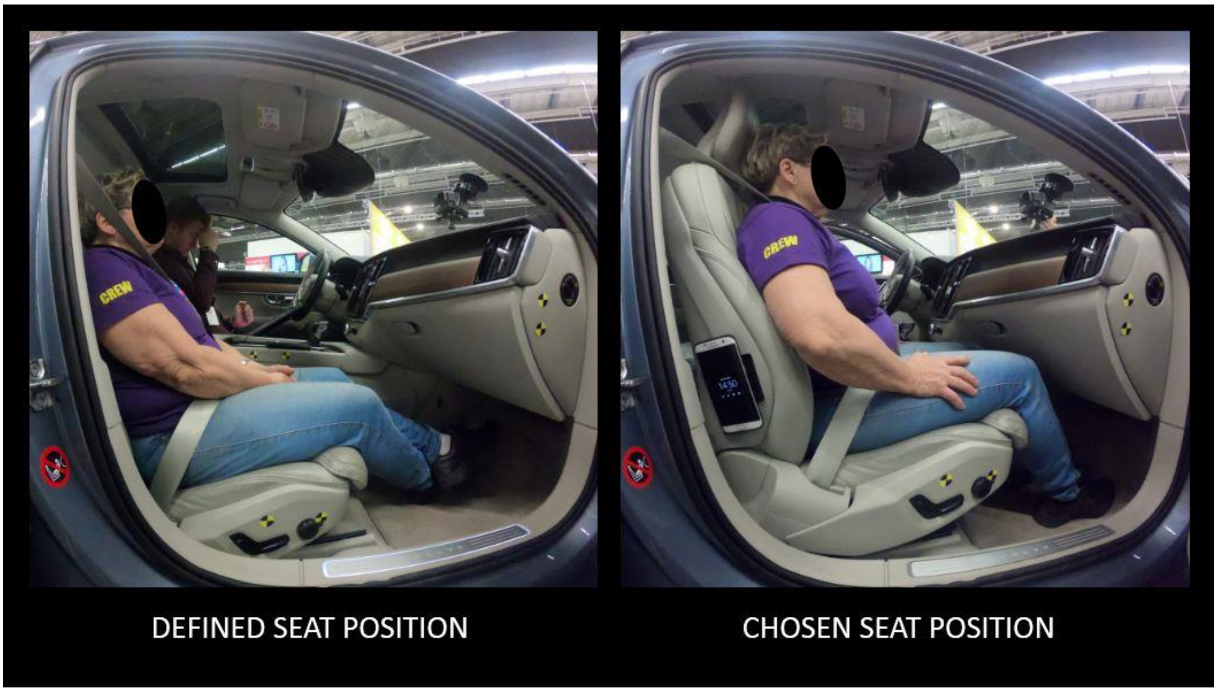


Figure 5.5 - Picture showing a participant noticeable increasing the seat height in the chosen position.

5.8 Summary of results: Comparing young and old passengers

The results presented below are based on the comparison between the 11 old and 11 young subjects participating in the comparative study.

- No difference was found regarding how the older target group sit in the car compared to the young reference group since both normally travel as drivers or passengers in the front seat.
- Compared to the young, the older group travel by car more often (weekly) compared to most of the younger group who are traveling less than 1 time a week.
- There were no differences in the number of participants who experienced discomfort in the test car between young and old. However, only the young reference group reported discomfort to several body regions.
- Discomfort in test car:
  Only the young reference group reported more than one discomfort. Both groups reported discomfort caused by the fixed headrest.
  - Discomfort among young:
    Perceived in lower back (bad back support), back of the head (disliked the headrest), underneath the knee (bad support under the knee) and back thigh and neck (too narrow seat base and could not adjust head rest).
  - Discomfort among old:
    Perceived in the neck (Could not tilt it backwards as wanted) and (Shoulder belt in contact with neck), bottom (felt like sitting in a bowl)
- In the young reference group 5 out of 11 had previous experience of discomfort caused by the seat belt being in contact with the neck. No result was gathered regarding the older group since the questions were added later in the project. Only two of the old got the question but none of them had previous experienced discomfort related to the seat belt.
- Regarding seat adjustments, more elderly normally adjusted the seat height compared to the young. A good field of sight outside the front window and observing and the traffic and red lights when somebody else drives the car was mentioned as reasons why.
- The old participants have more forward head postures (lesser CVA) compared to the young.
- In the comparative study a trend was found regarding the chosen seat height among the older group compared to the young reference group. Six out of 11 in the older target group increased the seat height noticeable (3 female and 3 male) and in the younger group one increased the seat height noticeable.

6. Seat belt fit at exhibition

In this chapter the result from the analysis of the photographs taken at the exhibition and the body data collected is presented. It includes the assessments of shoulder, lap and overall belt fit as well as the analysis of body related data in the defined seat positions which may influence belt fit. Since the seat belt height adjustment difference, in the defined position 1 and 2, only affects the shoulder belt fit, all 55 participants were analyzed as one group on the lap belt fit. Examples of photographs that were taken of the participants, their body data and the assessment of their seat belt fit can be seen in Appendix 7.

6.1 Shoulder belt fit

The shoulder belt fit was judged separately in the defined seat position 1, defined seat position 2 and the participants chosen seat position following the steps in “3.4.2 Defining belt fit parameters”. This part includes the subjective judgements on how it was placed on the shoulder, abdomen and if the belt was in contact with the body from the chest to the shoulder from a side view perspective. Furthermore, the results from the objective measurements of the shoulder belt angle and the distance from suprasternal notch to the upper edge of the seat belt are presented.

6.1.1 Shoulder belt position on shoulder

Figure 6.1 illustrates an example of how the shoulder belt was judged across the tip of the shoulder, in contact with neck and in the mid portion of the shoulder.

Figure 6.1 - Examples of participants judged to have the shoulder belt positioned tip, neck and mid.

Defined seat position 1 and 2

In the defined seat position 1 (shoulder belt height adjusted to level 2) 81% (26) had the shoulder belt positioned over the mid portion of the shoulder, 13% (4) had the shoulder belt positioned across the tip of the shoulder, 6% (2) had the shoulder belt in contact with the neck and 0% (0) had the shoulder belt positioned off the shoulder (figure 6.2).

In the defined seat position 2 (shoulder belt height adjusted down to level 1), 90% (18) had the shoulder belt positioned over the mid portion of the shoulder, 10% (2) had the shoulder belt positioned across the tip of the shoulder, 0% (0) had the shoulder belt in contact with the neck and 0% (0) had the shoulder belt positioned off the shoulder (figure 6.2).

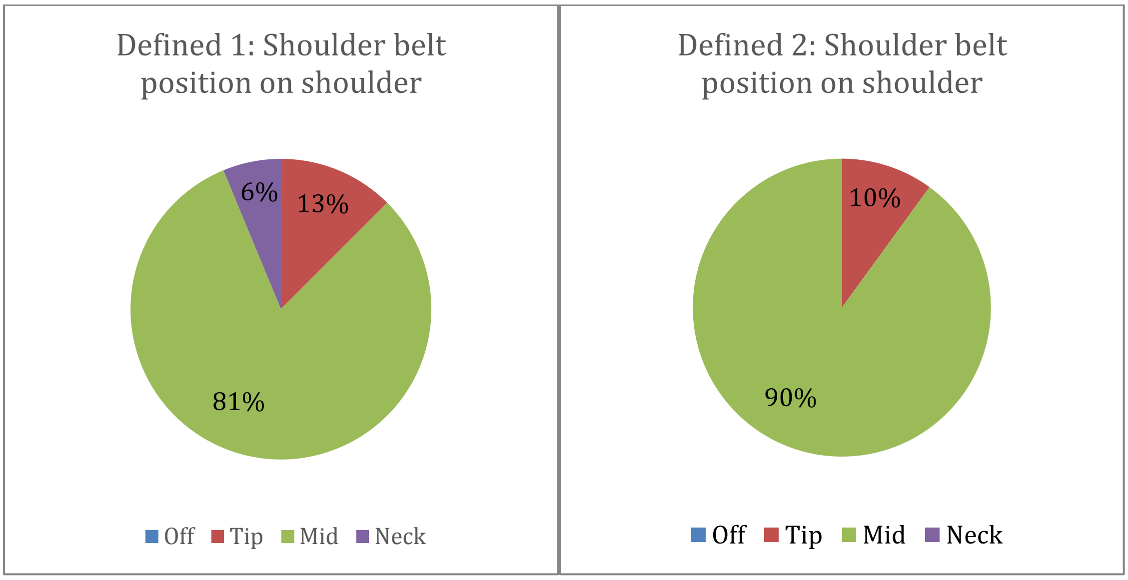


Figure 6.2 - Circle diagrams showing the percentage of participants placing the shoulder belt off, tip, mid and neck in the defined position 1 and 2.

Chosen seat position

In the chosen seat position, 75 % (41) of the participants had the shoulder belt positioned over the mid portion of the shoulder, 16% (9) of the participants had the shoulder belt positioned across the tip of the shoulder, 9% (5) of the participants had the shoulder belt in contact with the neck and 0% (0) of the participants had the shoulder belt positioned off the shoulder (figure 6.3).

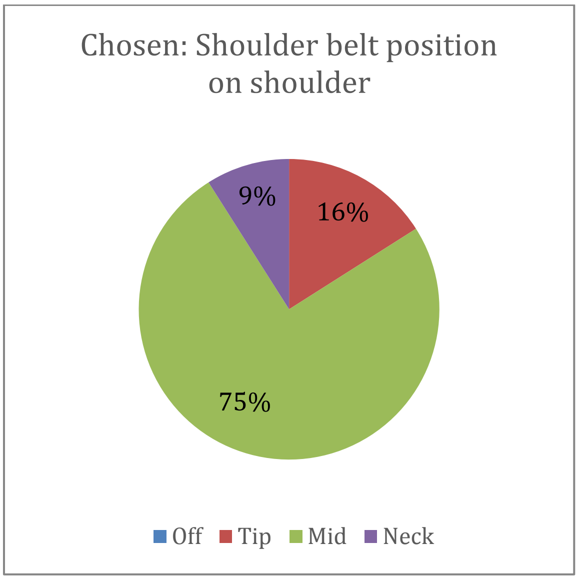


Figure 6.3 - Circle diagram showing the percentage of all participants having the shoulder belt off, tip, mid and neck in their chosen position.

6.1.2 Shoulder belt contact from chest to shoulder

Figure 6.4 illustrates an example of how the shoulder belt contact from chest to shoulder was judged in contact or not in contact.

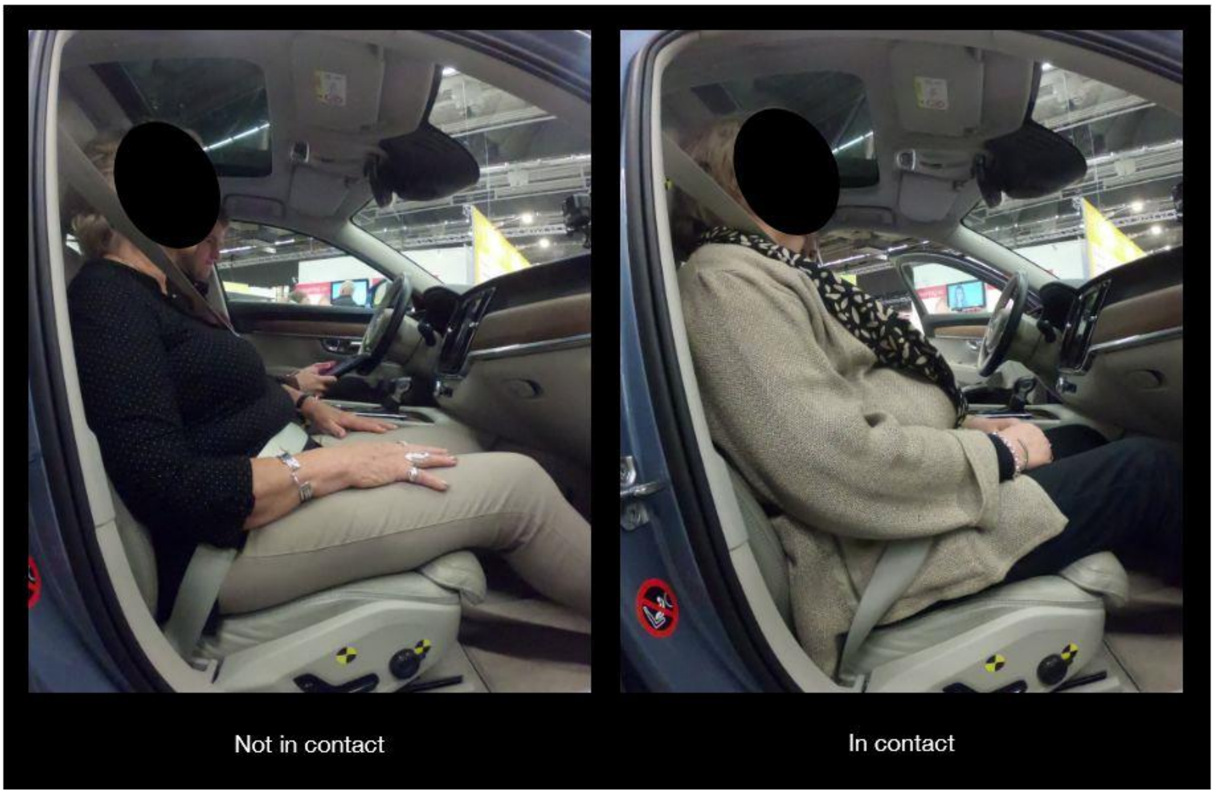


Figure 6.4 - Pictures showing an example when the shoulder belt was judged not in contact and in contact.

Defined seat position 1 and 2

Figure 6.5 describes, in percentage, how many of the participants in the defined seat position 1 and 2 that had the shoulder belt in contact from chest to shoulder or not. In the defined seat position 1, 84% (27), had the shoulder belt in contact and 16% (5), did not have the shoulder belt in contact. In the defined seat position 2, 85% (17), had the shoulder belt in contact and 15% (3), did not have the shoulder belt in contact.

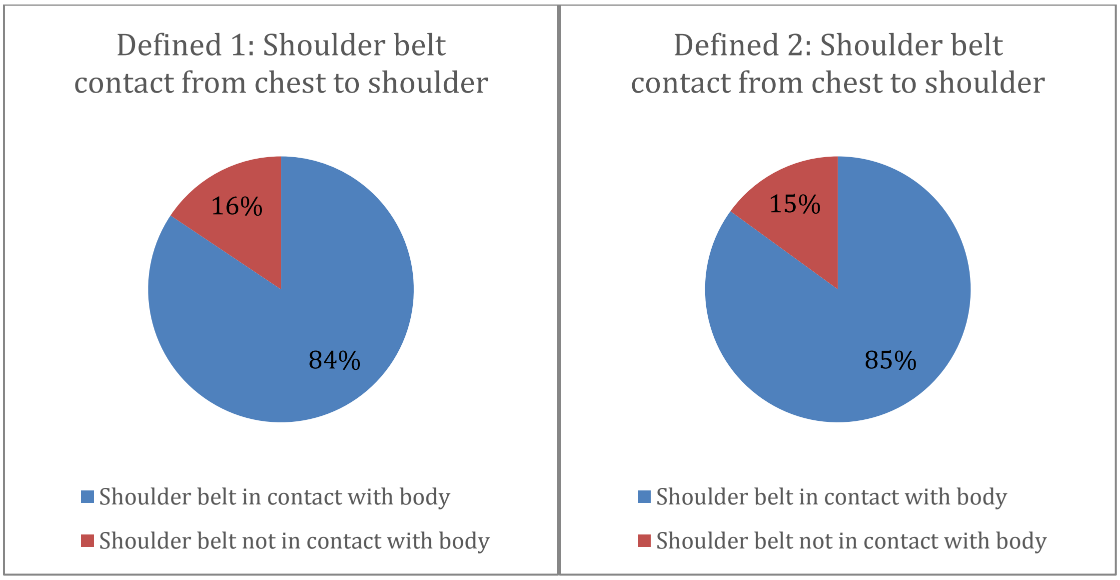


Figure 6.5 - Circle diagrams showing the percentage of participants judged in contact, in the defined position 1 and 2.

Chosen seat position

In the chosen seat position, 82% (45) of the participants did have the shoulder belt in contact and 18% (10) did not have the shoulder belt in contact (figure 6.6).

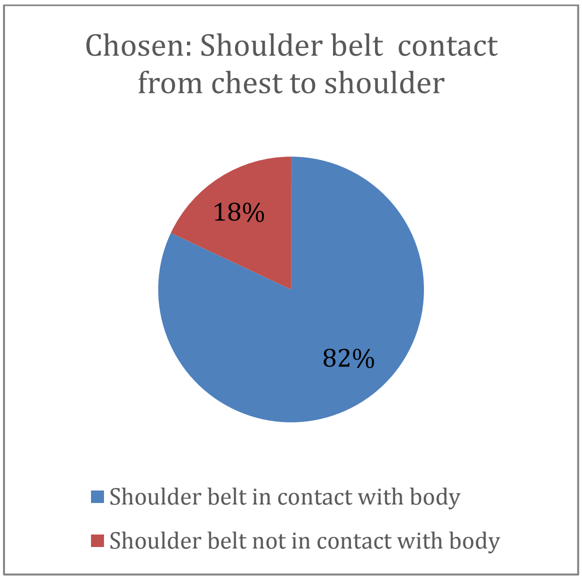


Figure 6.6 - Circle diagrams showing the percentage of participants judged in contact or not in contact, in the chosen seat position.

6.1.3 Shoulder belt position in relation to abdomen

Figure 6.7 illustrates an example of when the shoulder belt position in relation to the abdomen was judged high, mid, or low.

Figure 6.7 - Pictures showing examples of participants judged high, mid and low on abdomen.

Defined seat position 1 and 2

In the defined seat position 1, 47% (15) of the participants had the shoulder belt positioned high in relation to the abdomen, 34% (11) mid, and 19% (6) low (Defined 1 in figure 6.8).

In the defined seat position 2, 45% (9) of the participants had the shoulder belt positioned high in relation to the abdomen, 30% (6) mid, and 25% (5) low (Defined 2 in figure 6.8).

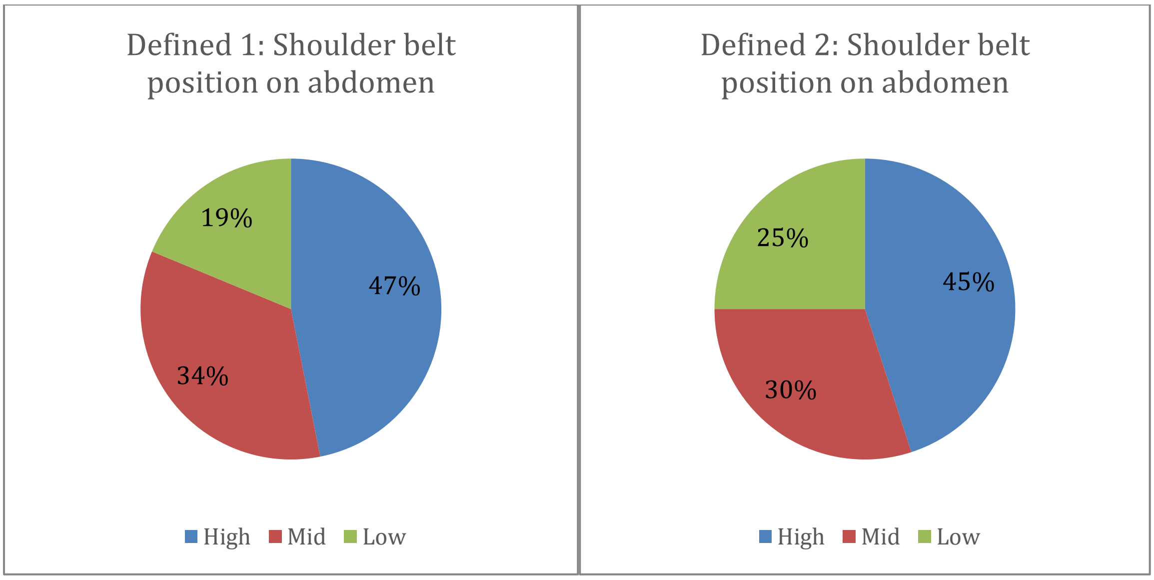


Figure 6.8 - Circle diagrams showing in percentage of participants judged high, mid and low on abdomen in the defined position 1 and 2.

Chosen seat position

In the chosen seat position, 65% (36) of the participants had the shoulder belt positioned high in relation to the abdomen, 24% (13) mid, and 11% (6) low (figure 6.9). These findings show a trend that the number of participants with the shoulder belt positioned high on the abdomen increases in the chosen position compared to the defined position.

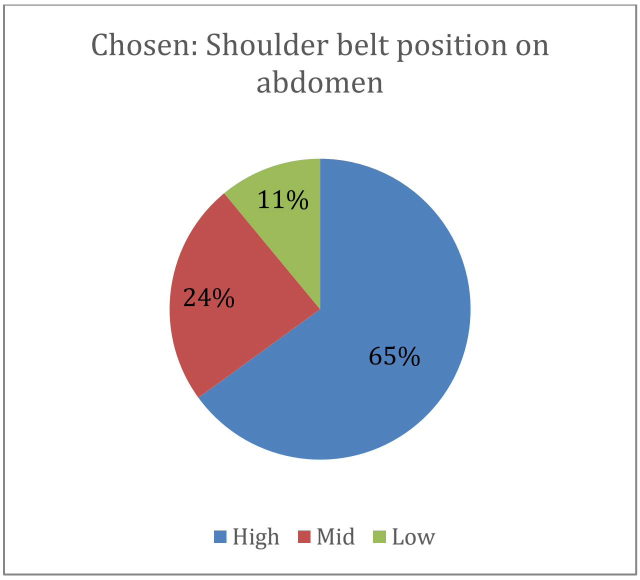


Figure 6.9 - Circle diagrams showing in percentage of participants judged high, mid and low on abdomen in the chosen position.

6.1.4 Shoulder belt angle and distance

The average shoulder belt angle measured in the photos was 43 degrees in both the defined seat position 1 and 2. Regarding the distance between the suprasternal notch and the upper edge of the seat belt the average was 57mm in the defined seat position 1 and 61mm in seat position 2. A comparison between shoulder belt angles and distance can be seen in figure 6.10. The trend show that the shoulder belt angle and distance influence each other. A larger angle results in a shorter distance.

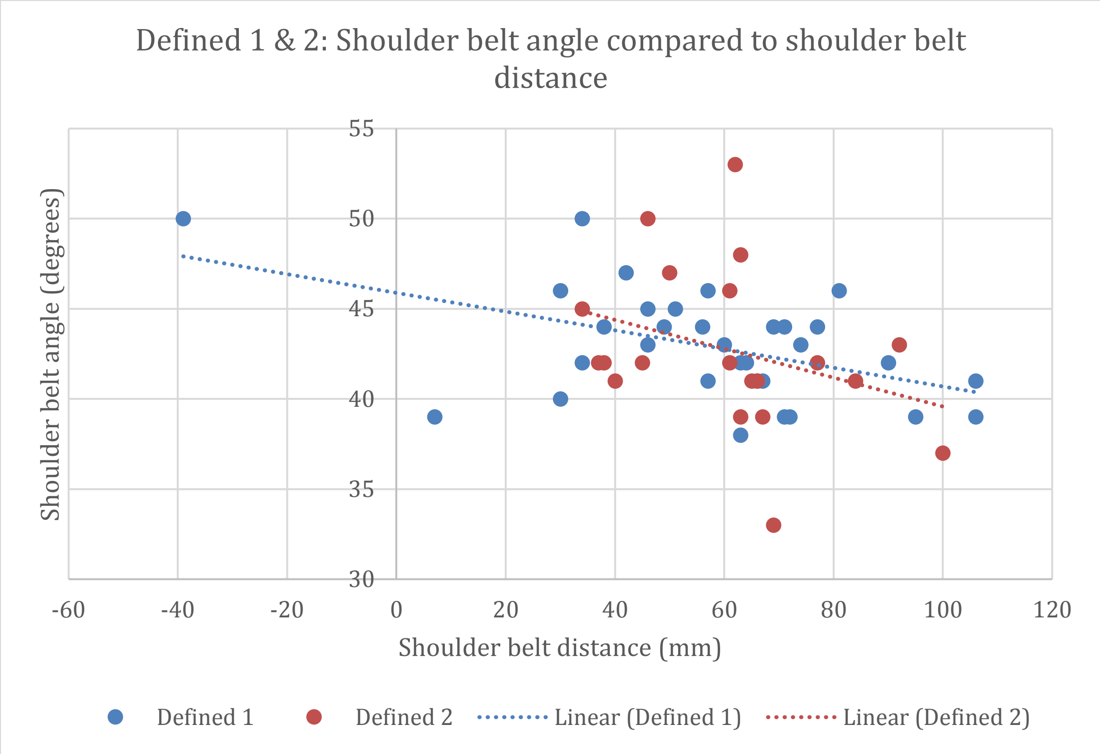


Figure 6.10 - Comparison between shoulder belt distance and angle in the defined position 1 and 2.

When looking at the shoulder belt angle and distance in the chosen seat position among all 52 participants the average distance decreased to 56mm in the chosen seat position compared to 57 and 61 in the defined positions. The average shoulder belt angle still had an average of 43 degrees as in defined position 1 and 2. Thus, no trend was found that lowering the shoulder belt height one level changes the shoulder belt angle.

6.1.5 Summary of results: Shoulder belt fit

The results presented below are based on the findings among the participants at the exhibition.

Shoulder belt position on shoulder

- Slightly more participants had the shoulder belt positioned across the tip of the shoulder and in contact with the neck while seated in the chosen seat position than in the defined seat position 1 and 2.

Shoulder belt contact from chest to shoulder

- No differences were found between the defined seat position 1 and 2 and the chosen seat position regarding shoulder belt contact with body from chest to shoulder.

Shoulder belt position in relation to the abdomen

- The findings show a trend that the number of participants with the shoulder belt positioned high on the abdomen increases in the chosen position compared to both the defined seat positions.

Shoulder belt angle

- No difference between the two defined seat positions and the chosen seat position were found regarding shoulder belt angle.

Shoulder belt distance to suprasternal notch

- The average shoulder belt distance to suprasternal notch was 56mm in the chosen seat position, 57mm in the defined seat position 1 and 61mm in the defined seat position 2.

6.2 Factors influencing shoulder belt fit in defined seat positions

The defined seat position 1 and 2 were then used to further analyze the shoulder belt fit compared to gender, BMI, stature, waist and hip circumference.

6.2.1 Shoulder belt position on shoulder

The shoulder belt position on shoulder was compared between genders and to BMI, waist and hip circumference as well as to stature.

Gender

In the defined seat position 1, 80% (16) of the male participants had the shoulder belt positioned over the mid portion of the shoulder and 20% (4), had the shoulder placed across the tip of the shoulder. Among the female participants, in the defined seat position 1, 83% (10) had the shoulder belt positioned over the mid portion of the shoulder and 17% (2) had the shoulder belt positioned in contact or close to the neck (figure 6.11).

In the defined seat position 2 the results were the same for both males and females, 90 % (9) had the shoulder belt positioned over the mid portion of the shoulder and 10 % (1) had the shoulder belt positioned across the tip of the shoulder. (figure 6.11).

These findings show that the male participants more commonly had the shoulder belt positioned across the tip of the shoulder than the females and that the female participants more commonly had the shoulder belt positioned in contact or close to the neck than the males in the defined seat position 1. In the defined seat position 2, no difference was found between genders.

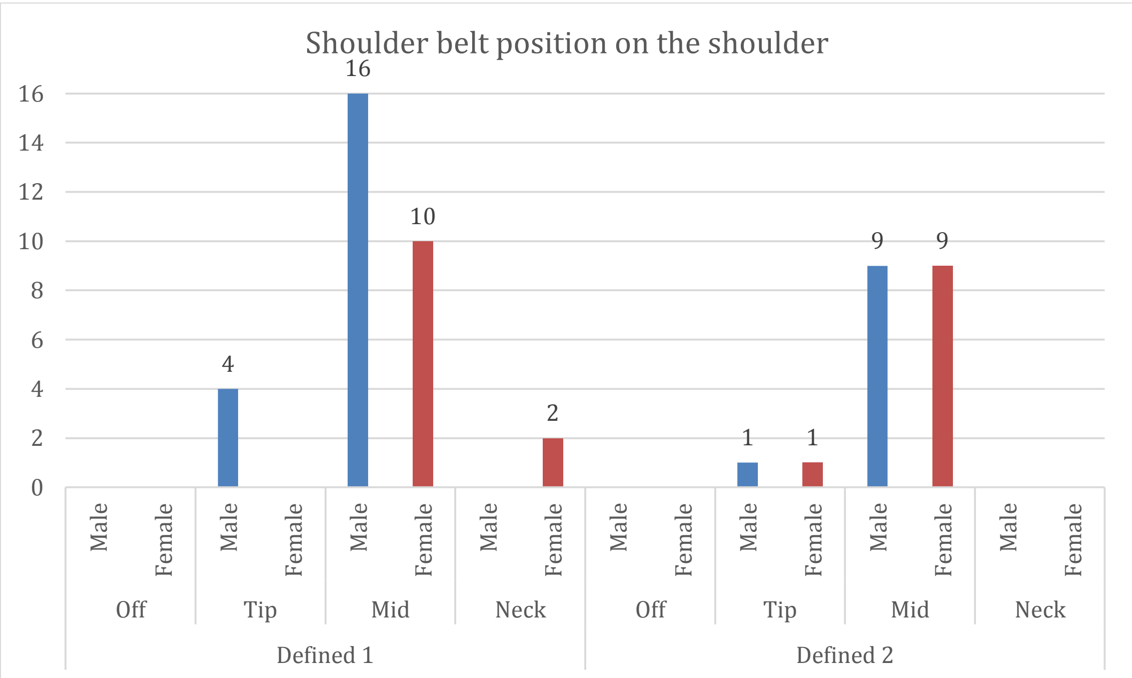


Figure 6.11 - Comparing the number of males and females in the defined position 1 and 2 judged positioned off, tip, mid or neck on the shoulder.

BMI

The shoulder belt position on shoulder was then compared to the BMI categories; underweight, normal, overweight, and obese. In the defined seat position 1, the result shows that a shoulder belt positioned across the tip of the shoulder was most common within the overweight BMI category among the male participants (figure 6.12). However, a shoulder belt positioned over the mid portion of the shoulder or in contact/close to the neck, do not seem to be affected by BMI in neither the defined seat position 1 or 2 (figure 6.12 & 6.13).

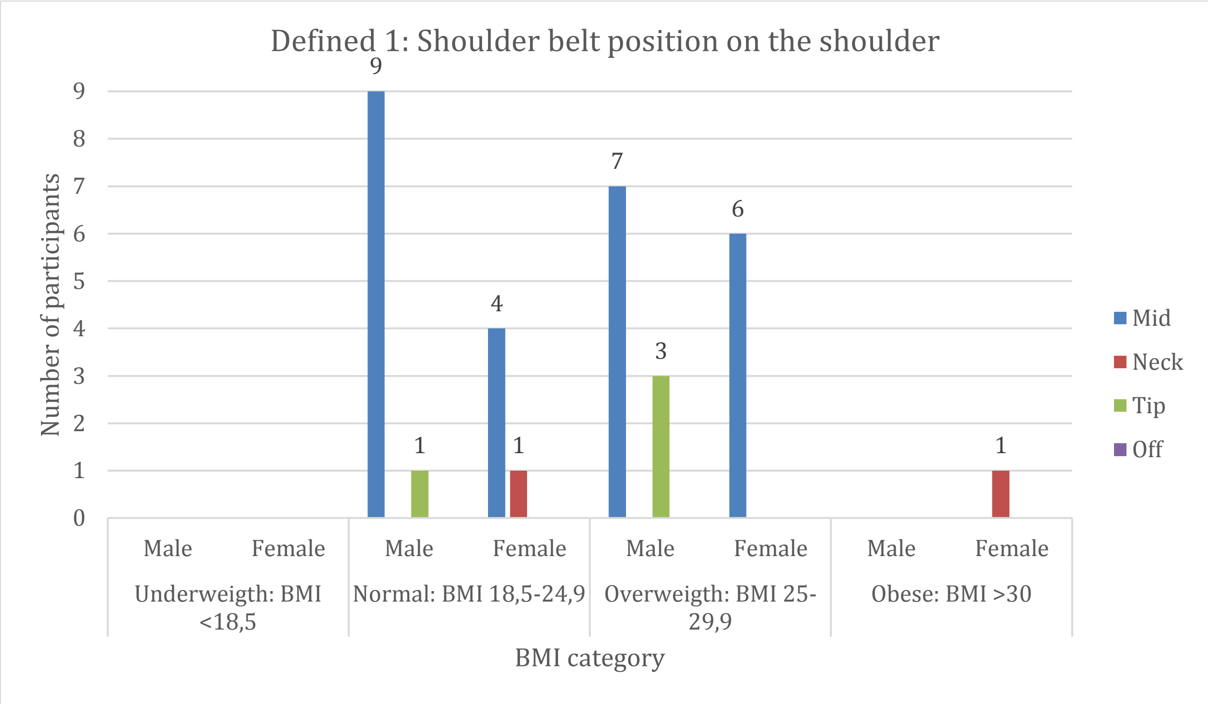


Figure 6.12 - Showing the number of participants judged positioned off, tip, mid or off the shoulder in the different BMI categories in defined position 1.

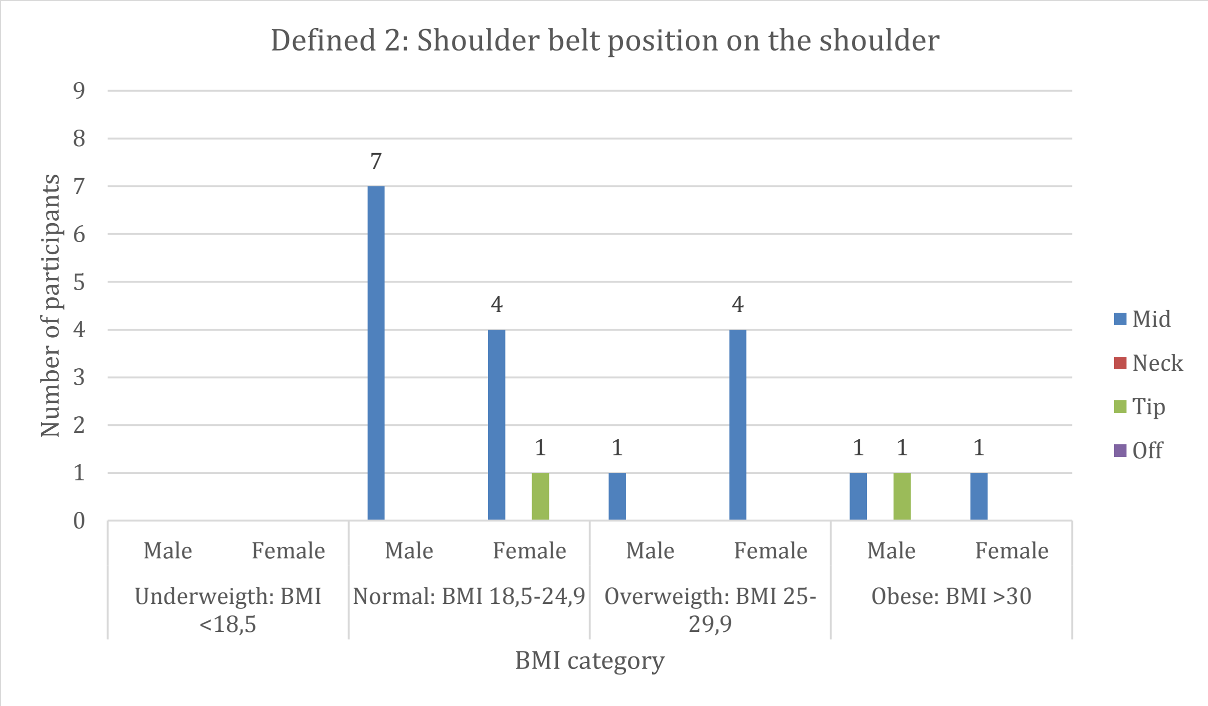


Figure 6.13 - Showing the number of participants judged positioned off, tip, mid or off the shoulder in the different BMI categories in defined position 2.

Waist and hip circumference

When comparing the shoulder belt position on the shoulder to waist and hip circumference, no trend was found. This was the case for both defined seat positions (figure 6.14 – 6.17). This suggest that the shoulder belt position on the shoulder is not largely influenced by waist or hip circumference.

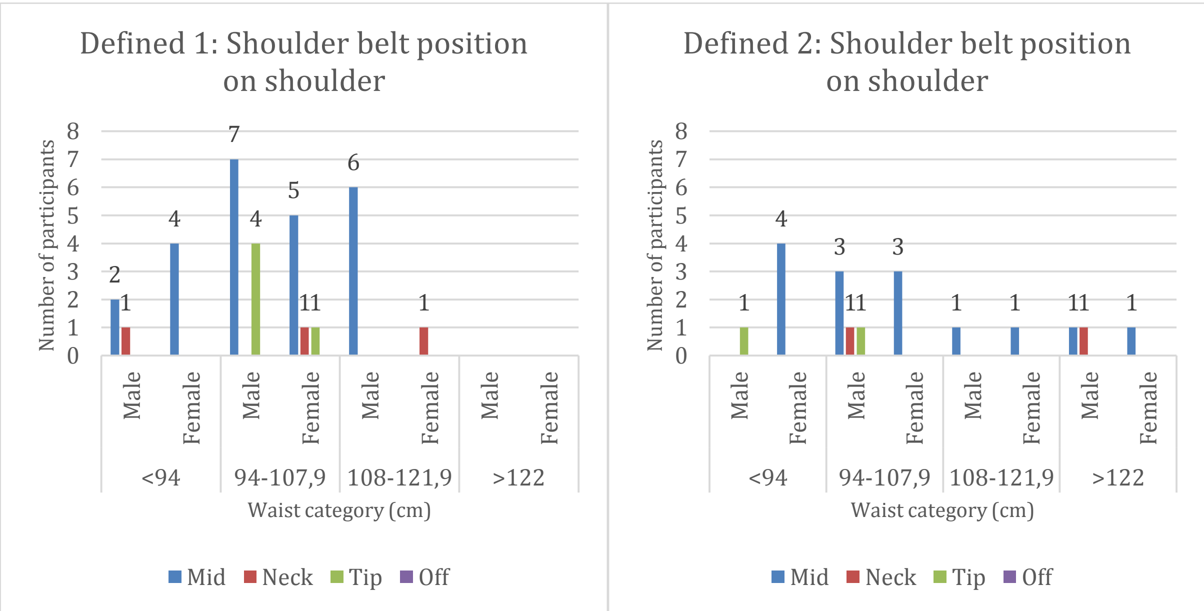


Figure 6.14 & 6.15 – Shoulder belt position on shoulder compared to waist circumference, in defined seat position 1 & 2.

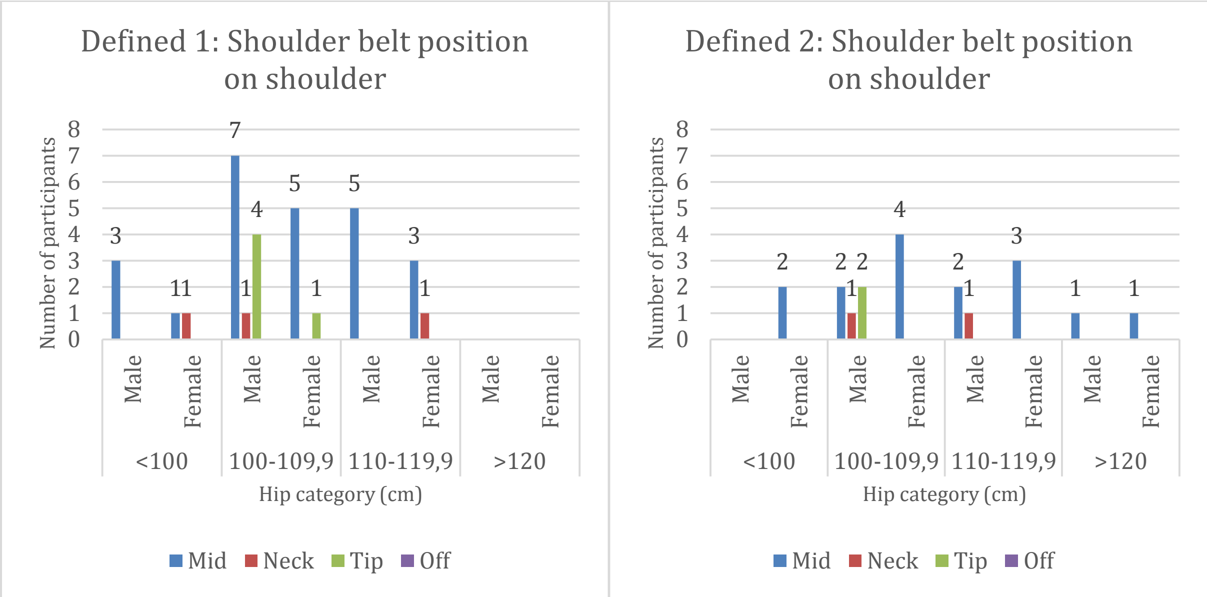


Figure 6.16 & 6.17 – Shoulder belt position on shoulder compared to hip circumference, in defined seat position 1 & 2.

Stature

When comparing the shoulder belt position on the shoulder to stature, the result shows that no participants below 170 cm in stature demonstrate a shoulder belt positioned across the tip of the shoulder. The result also shows that no participant outside the range 160 cm to 169 cm in stature demonstrate a shoulder belt positioned in contact or close to the neck. Furthermore, the result shows that a shoulder belt positioned over the mid portion of the shoulder appear in all stature categories (figure 6.18). These findings apply to both the defined seat position 1 and 2. However, in the defined seat position 2, the result display that no participants below 180 cm in stature demonstrate a shoulder belt positioned across the tip of the shoulder (figure 6.19).

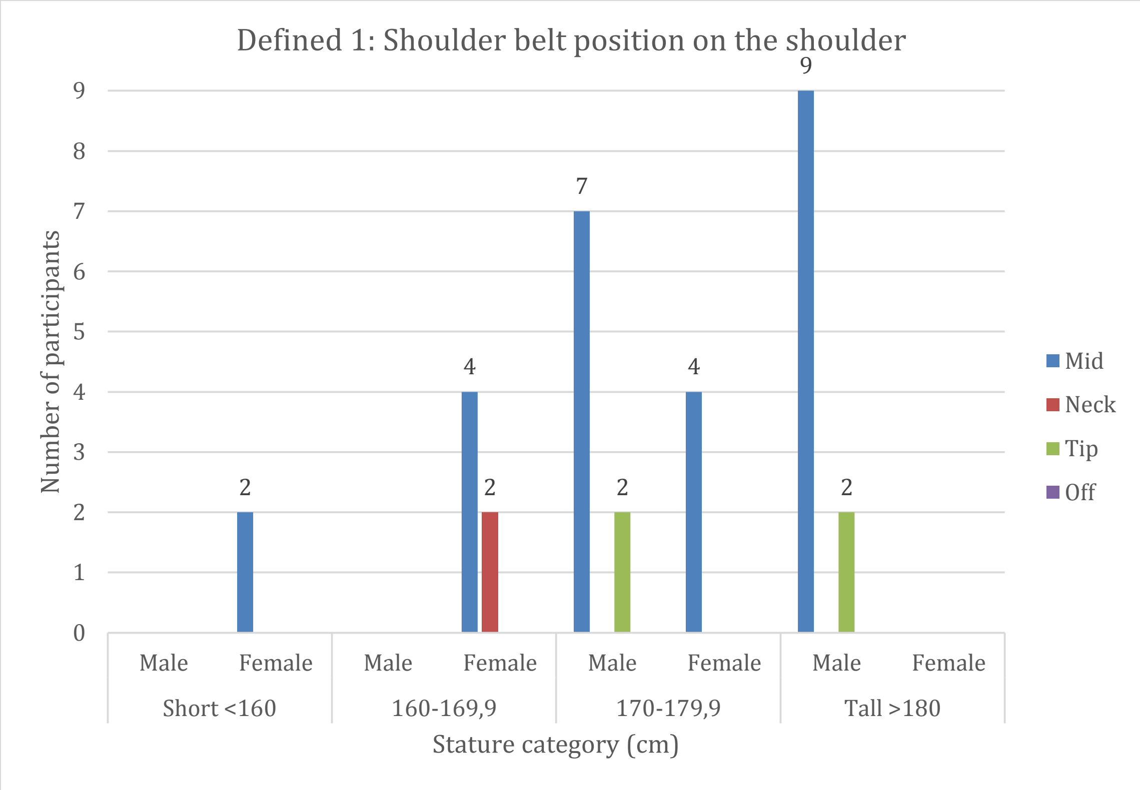


Figure 6.18 - Showing the number of participants judged positioned off, tip, mid or neck the shoulder in the different stature categories in defined position 1.

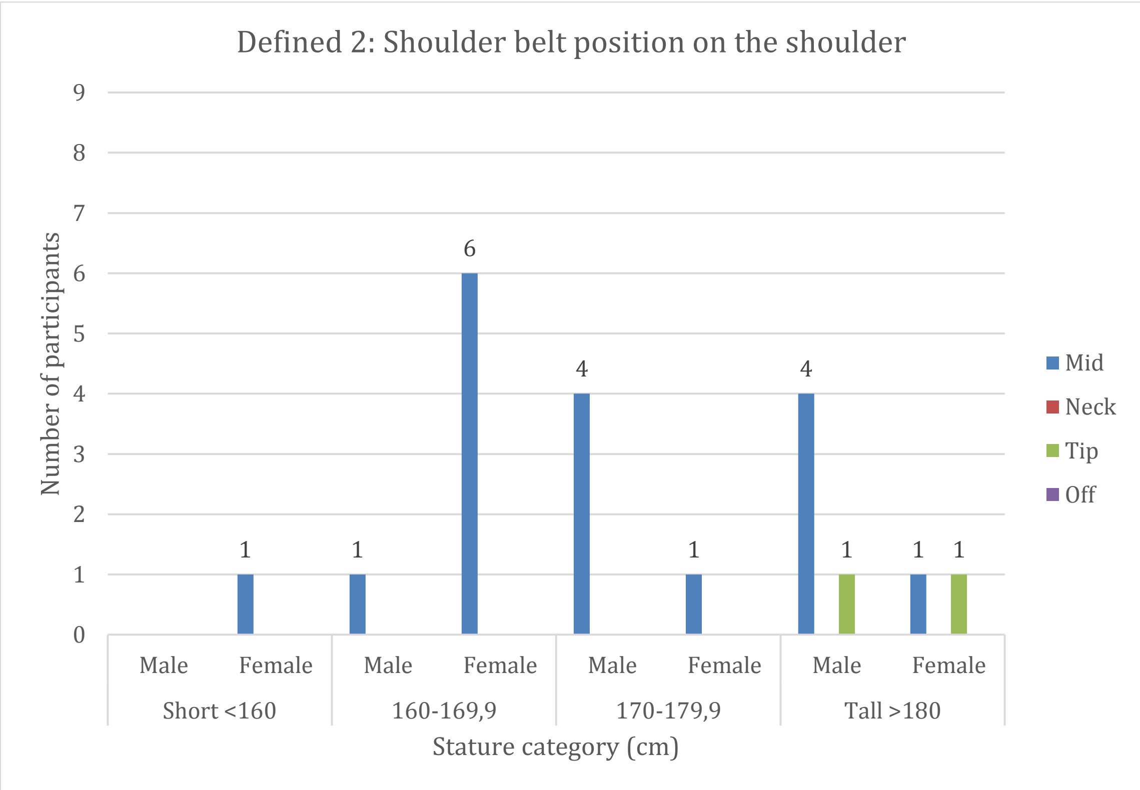


Figure 6.19 - Showing the number of participants judged positioned off, tip, mid or neck the shoulder in the different stature categories in defined position 2.

6.2.2 Shoulder belt contact from chest to shoulder

The shoulder belt contact with the body from chest to shoulder was compared between genders and to BMI. The findings suggest that more male than female participants demonstrate contact in the defined seat position 1. This trend was not found in the defined seat position 2. Furthermore, the findings do not indicate that BMI influence the shoulder belt contact from chest to shoulder.

Gender

The shoulder belt contact from chest to shoulder was compared between genders in both the defined seat position 1 and 2 (figure 6.20). The findings show that more male than female participants demonstrate contact in the defined seat position 1. However, this was not as prominent in the defined seat position 2.

In the defined seat position 1, among the male participants, 100% (20) demonstrated contact. Among the female participants 58 % (7), demonstrated contact and 42% (5), did not demonstrate contact. In the defined seat position 2, among the male participants 90 % (9) demonstrated contact and 10% (1) did not. Among the female participants, 80 % (8) demonstrated contact and 20% (2) did not (figure 6.20).

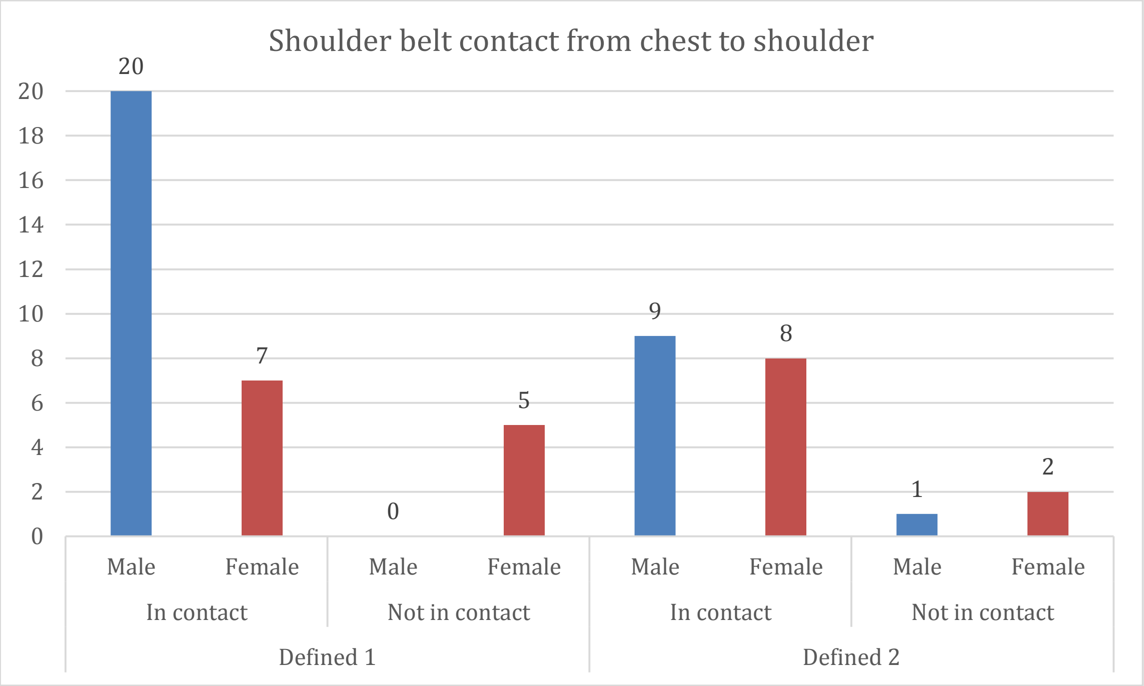


Figure 6.20 – Number of participants judged in contact or not in contact in the defined position 1 and 2.

BMI

The shoulder belt contact from chest to shoulder was compared between BMI categories for both the defined seat position 1 and 2 (figure 6.21 & 6.22). The findings do not indicate that BMI influence the shoulder belt contact from chest to shoulder.

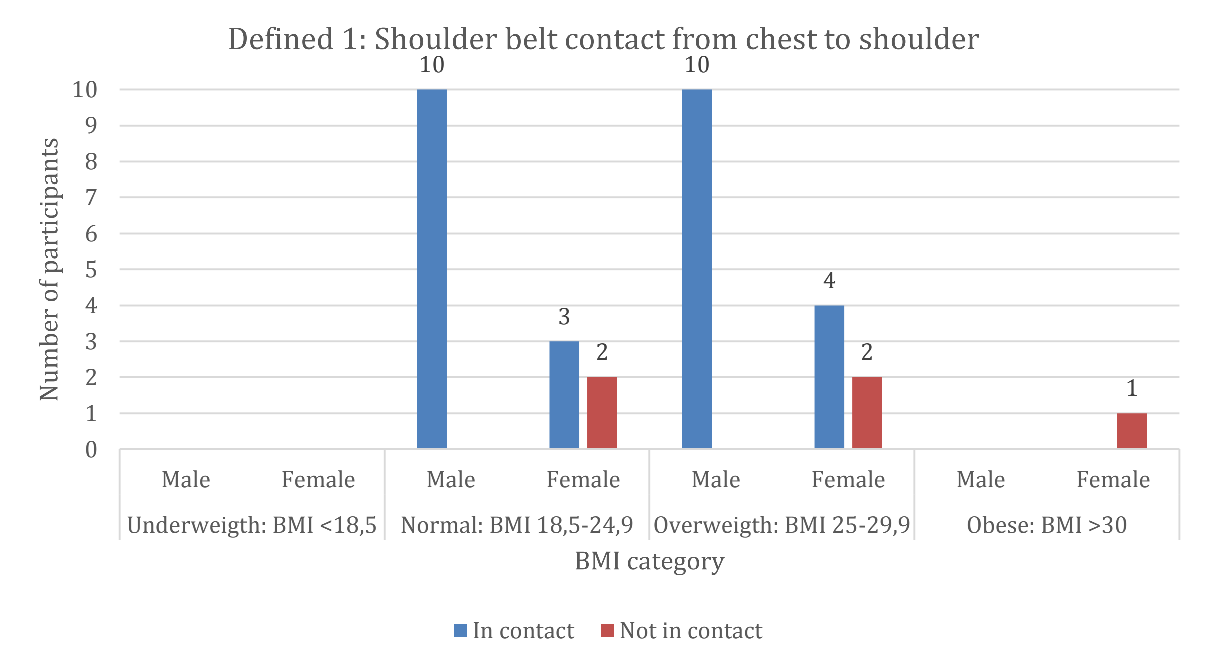


Figure 6.21 - Showing the number of participants judged in contact or not within different BMI categories in defined position 1.

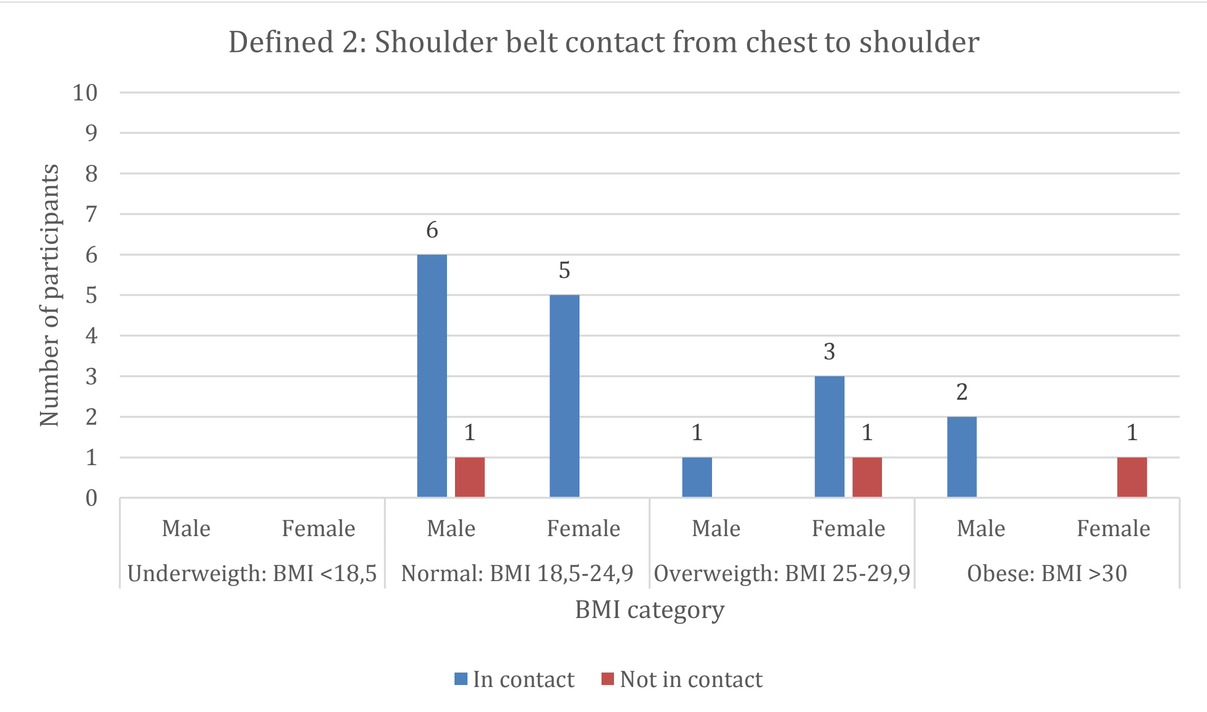


Figure 6.22 - Showing the number of participants judged in contact or not within different BMI categories in defined position 2.

6.2.3 Shoulder belt position in relation to abdomen

The result shows a trend that males and those with a higher waist and hip circumference as well as have a greater BMI are more likely to have the shoulder belt positioned higher on the abdomen. No trend was found regarding stature.

Gender

When comparing shoulder belt position on abdomen between genders, 50% (10) of the male participants had the shoulder belt positioned high in relation to the abdomen, 30% (6) mid and 20% (4) low in the defined seat position 1. Among the female participants, in the defined seat position 1, 42% (5) had the shoulder belt positioned high in relation to the abdomen, 42% (5) mid and 16% (2) low. In the defined seat position 2, 70% (7) of the male participants had it positioned high, 20% (2) mid and 10% low. Among the female participants, in the defined seat position 2, 20% (2) had it positioned high, 40% (4) mid and 40% (4) low (figure 6.23).

These results show a trend that having the shoulder belt positioned high in relation to the abdomen is more common among the male participants than among the female.

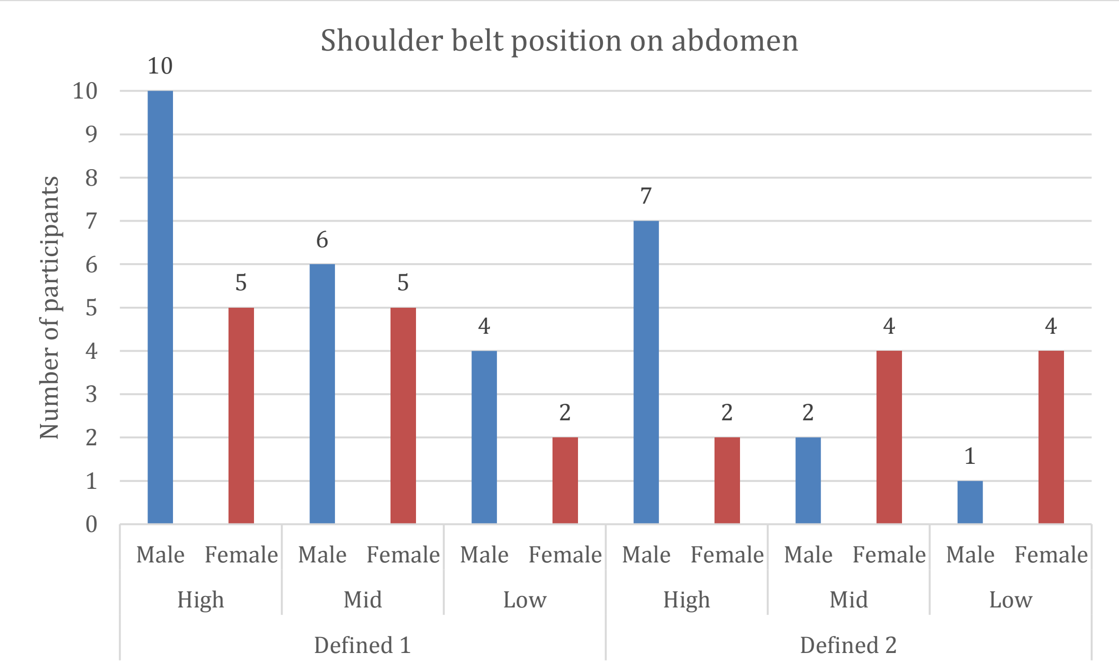


Figure 6.23 - Comparing the number of males and females shoulder belt judged high, mid or low on the abdomen in the defined position 1 and 2.

BMI

In the defined seat position 1, the result shows that participants within the higher BMI categories are more likely to position the belt high on the abdomen compared to those within the lower BMI categories. The trend shows that participants with the belt positioned high on the abdomen most often are overweight and those with the belt low on the abdomen are in the normal BMI category. Regarding the belt positioned mid in relation to the abdomen, no trend was found. However, no participants in the obese category had the belt positioned mid on the abdomen (figure 6.24).

In the defined seat position 2, no trend was found in BMI category affecting the shoulder position in relation to the abdomen. However, all participants in the obese category had the shoulder belt positioned high on the abdomen (figure 6.25).

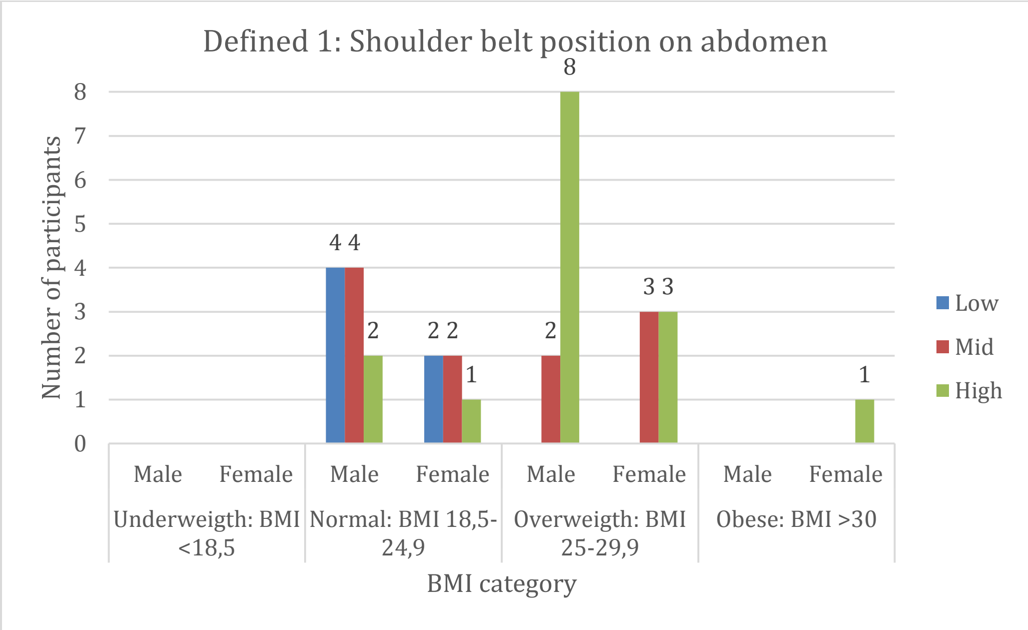


Figure 6.24 - Showing the number of participants judged positioned high, mid or low in different BMI categories in defined position 1.

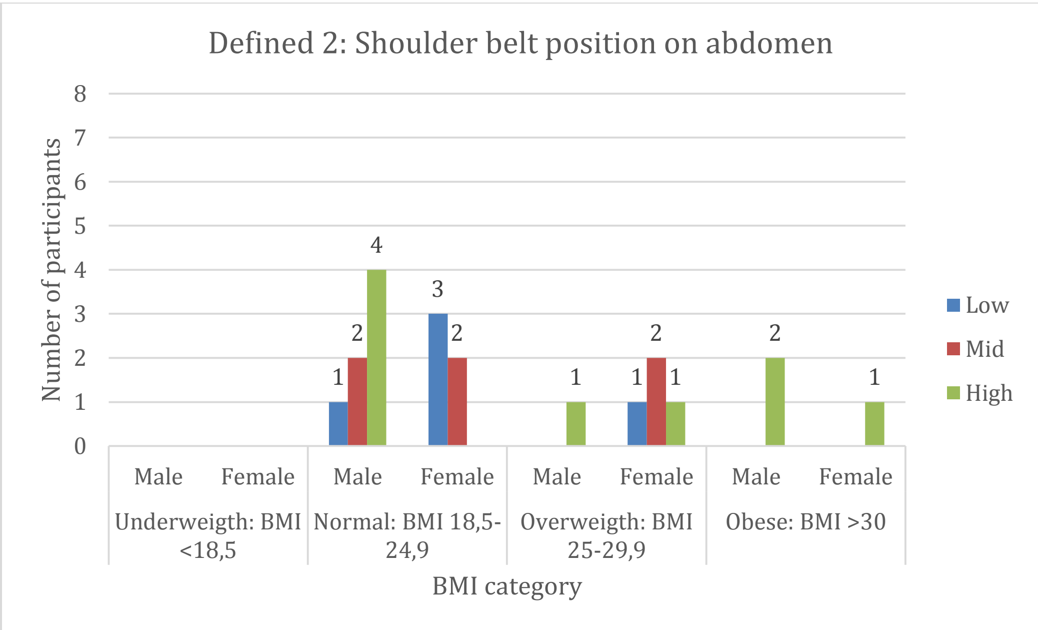


Figure 6.25 - Showing the number of participants judged positioned high, mid or low in different BMI categories in defined position 2.

Waist and Hip circumference

Regarding the waist circumference impact on the shoulder belt position on the abdomen, a higher position is more common among the participants within the greater waist categories. The majority of participants with the shoulder belt positioned low or mid on the abdomen appear with smaller waist circumference. This trend was found for both the defined seat position 1 and 2 (figure 6.26 & 6.27). Regarding the hip circumference impact on the shoulder belt position on the abdomen, a similar trend to the waist circumference impact was found for both the defined seat position 1 and 2 (figure 6.28 & 6.29).

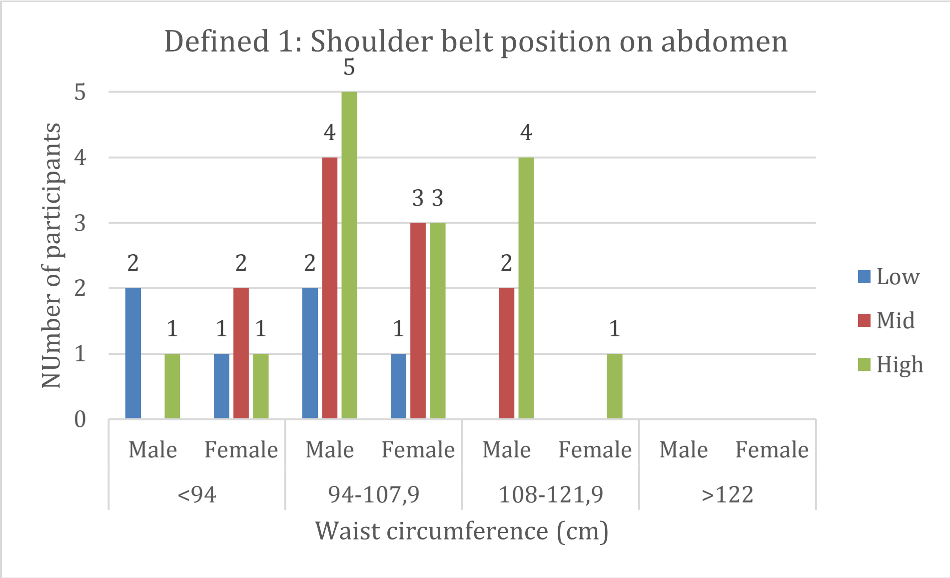


Figure 6.26 - Showing the number of participants judged low, mid and high on abdomen in different categories of waist circumference in the defined position 1.

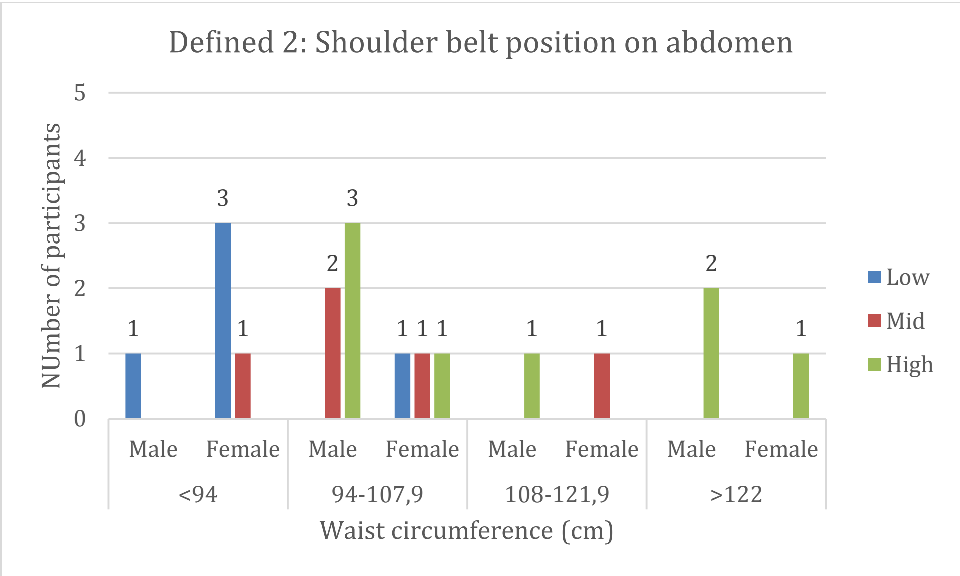


Figure 6.27 - Showing the number of participants judged low, mid and high on abdomen in different categories of waist circumference in the defined position 2.

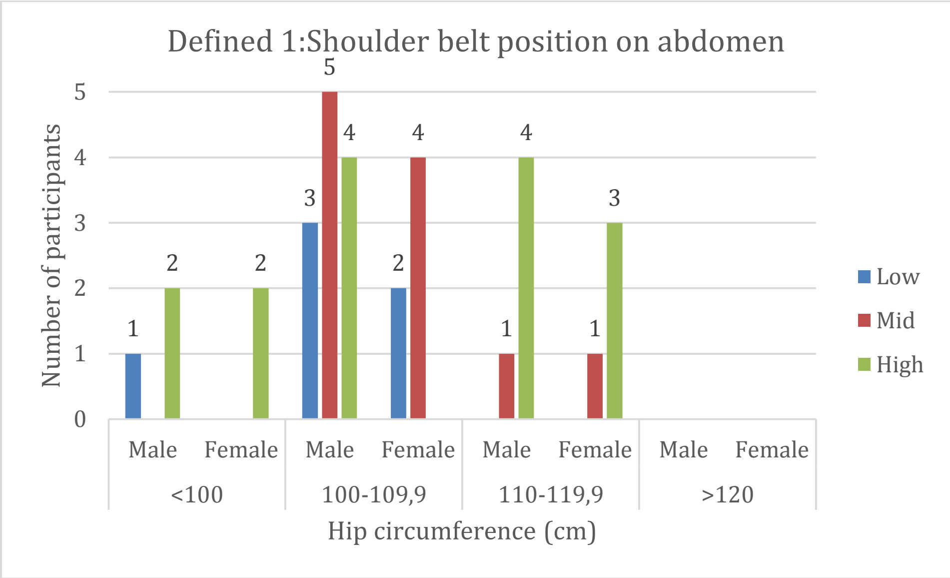


Figure 6.28 - Showing the number of participants judged low, mid and high on abdomen in different categories of hip circumference in the defined position 1.

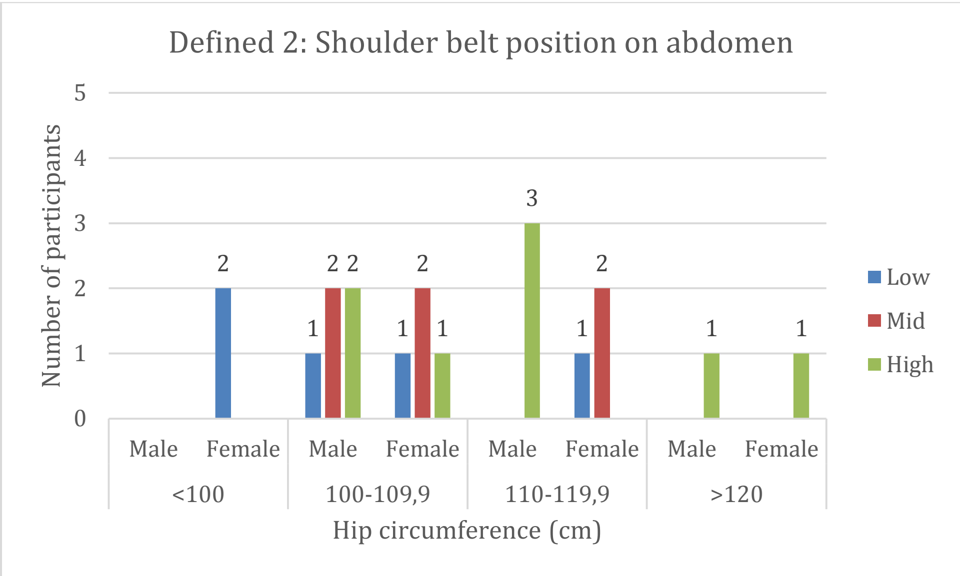


Figure 6.29 - Showing the number of participants judged low, mid and high on abdomen in different categories of hip circumference in the defined position 2.

Stature

When comparing the shoulder belt position on the abdomen to stature, no trend was found for either the defined seat position 1 or 2 (figure 6.30 & 6.31). This indicate that the shoulder belt position on the abdomen is not affected by stature.

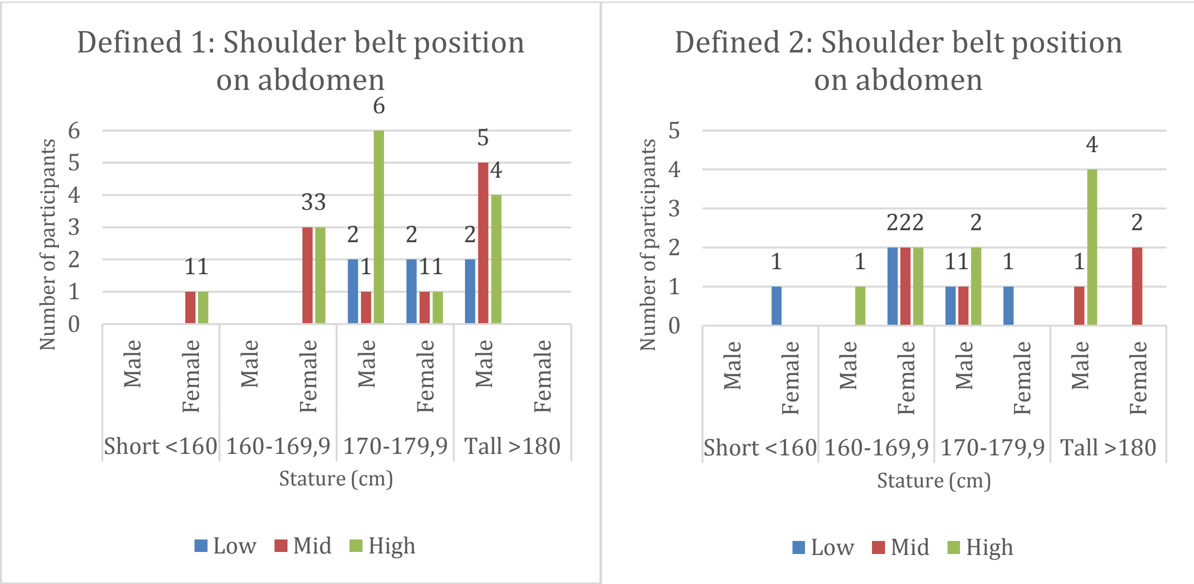


Figure 6.30 and 6.31 – Shoulder belt position on abdomen compared to stature, in the defined seat position 1 & 2.

6.2.4 Shoulder belt angle

The shoulder belt angle was compared between genders and to BMI, waist, stature and CVA. The findings indicate that increased BMI and waist circumference leads to increased shoulder belt angle for both genders. Shoulder belt angle compared to stature indicate a difference between the male and female participants in the defined seat position 1, where the shoulder belt angle increases as stature increases among the male participants and decreases as stature increases among the female participants. Comparing shoulder belt angle to CVA, the findings indicate that the shoulder belt angle increases with lower CVA, in the defined seat position 2. This trend was not found in the defined seat position 1.

BMI

When comparing shoulder belt angle to BMI a trend was found that the shoulder belt angle increases when BMI increases. This trend was found in both defined seat positions as well as for both genders (figure 6.32 & 6.33).

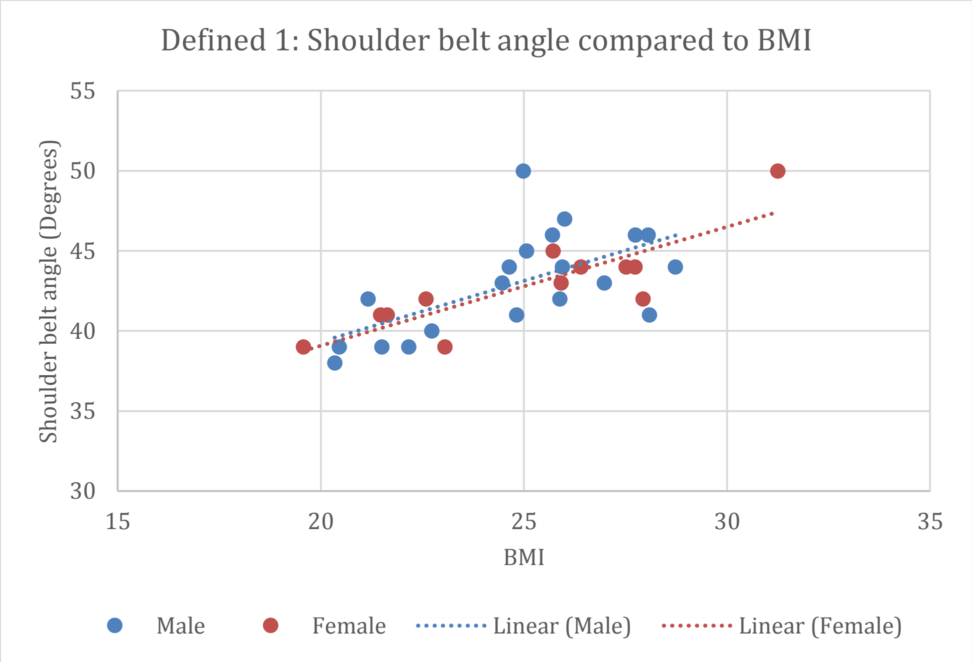


Figure 6.32 - Showing shoulder belt angle compared to BMI in the defined position 1.

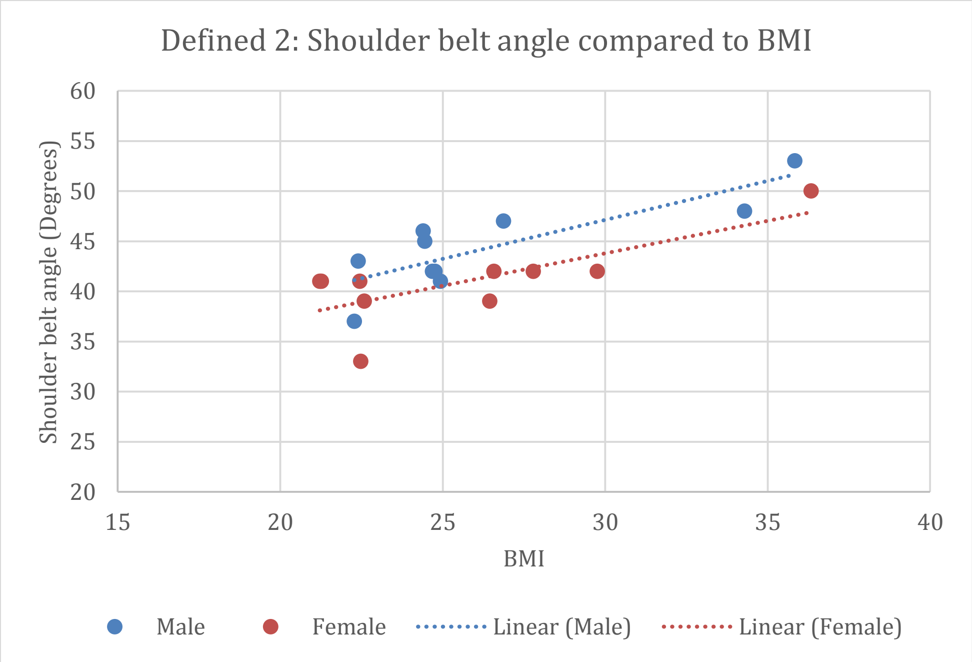


Figure 6.33 - Showing shoulder belt angle compared to BMI in the defined position 2.

Waist circumference

When comparing the shoulder belt angle to waist circumference, a trend was found that the shoulder belt angle increases with increasing waist circumference for both genders, and in both defined seat positions. This trend was found slightly more prominent among the male participants than among the female (figure 6.34 & 6.35)

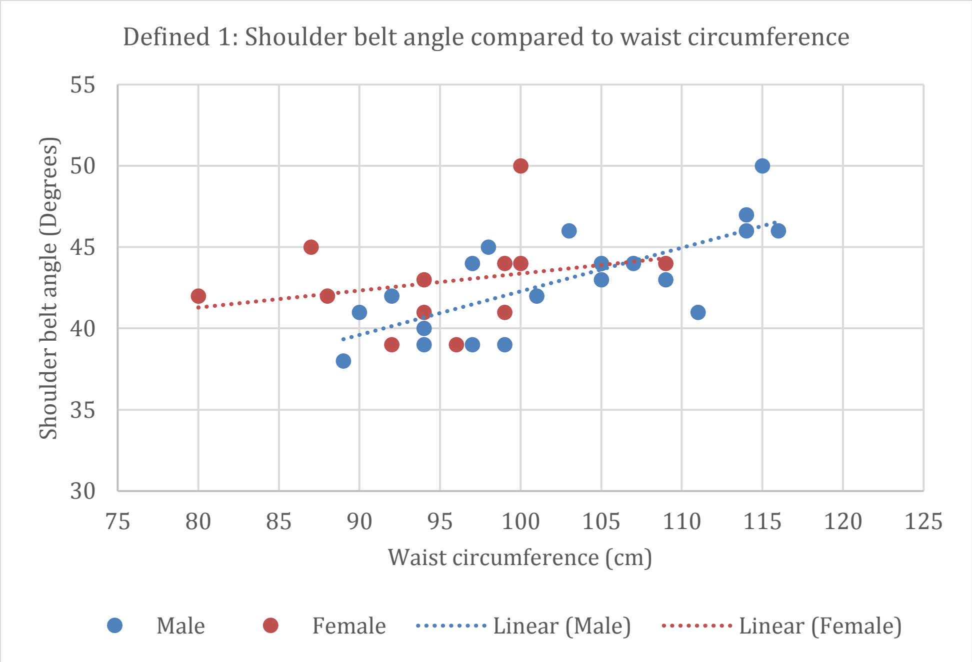


Figure 6.34 - Showing shoulder belt angle compared to waist circumference in the defined position 1.

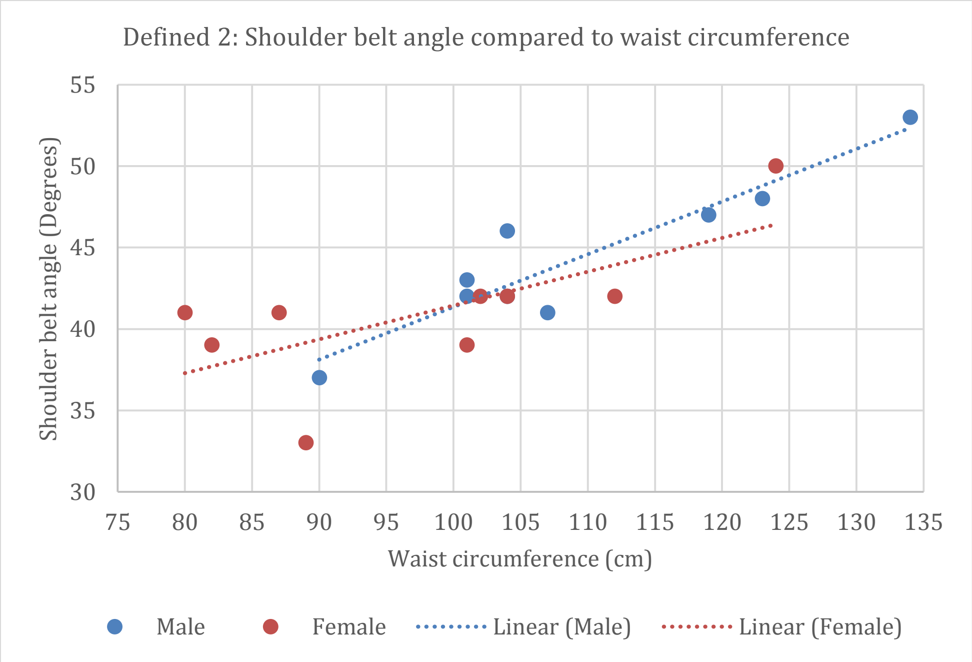


Figure 6.35 - Showing shoulder belt angle compared to waist circumference in the defined position 2.

Stature

Regarding shoulder belt angle compared to stature, a difference was found between the male and female participants in the defined seat position 1. Among the male participants, the shoulder belt angle increases as stature increases. Among the female participants, the shoulder belt angle decreases as stature increases (figure 6.36). In the defined seat position 2, no trend was found in stature affecting shoulder belt angle (figure 6.37).

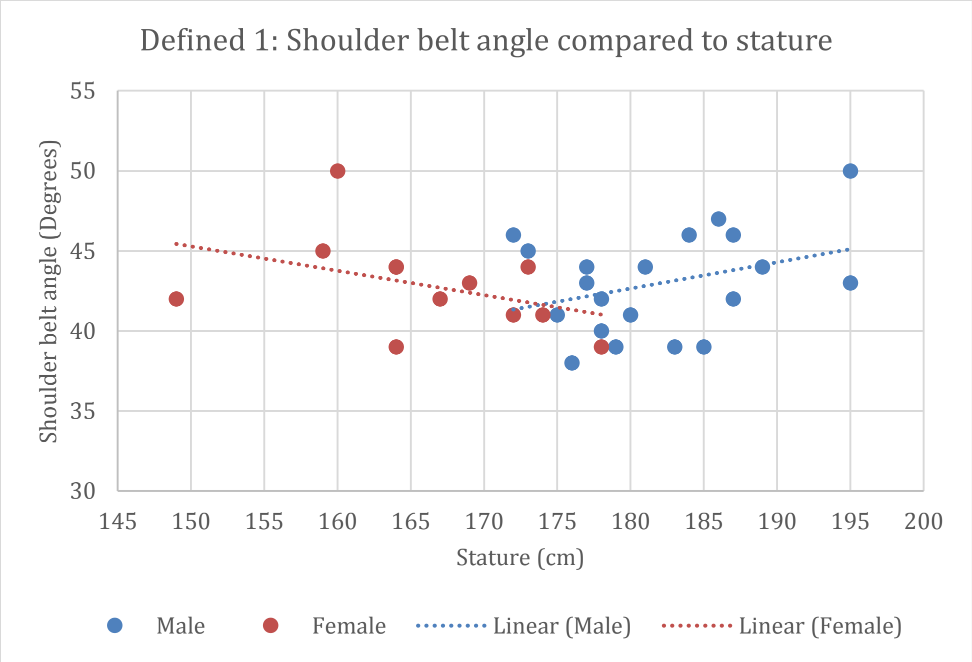


Figure 6.36 - Showing shoulder belt angle compared to stature in the defined position 1.

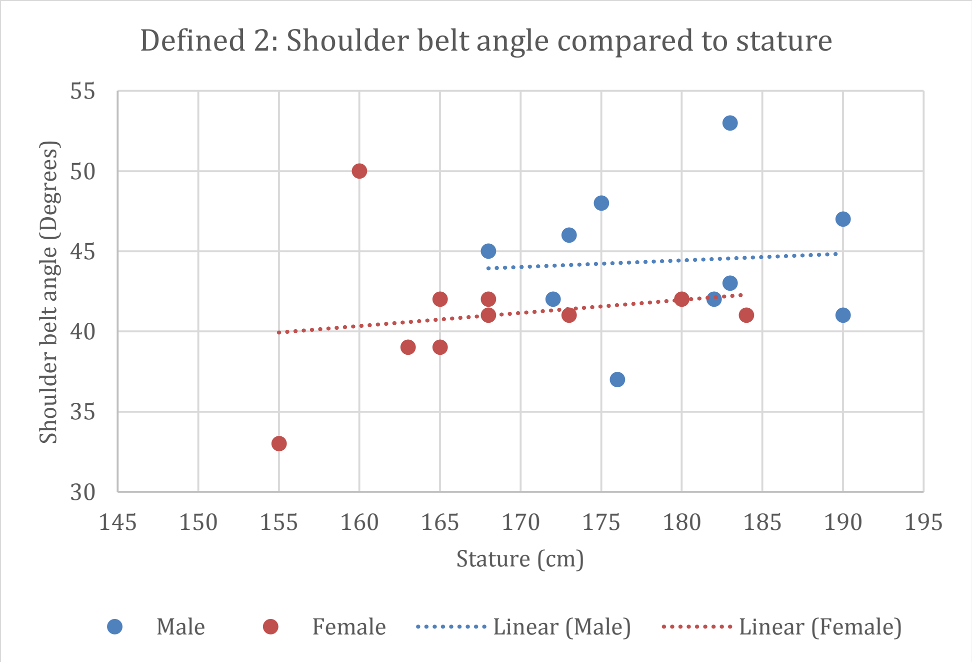


Figure 6.37 - Showing shoulder belt angle compared to stature in the defined position 2.

CVA

Regarding shoulder belt angle compared to the CVA, the findings indicate that, in the defined seat position 1, the CVA does not influence the shoulder belt angle among the participants (figure 6.38). In the defined seat position 2, the findings indicate a trend of that decreased CVA leads to greater shoulder belt angle (figure 6.39).

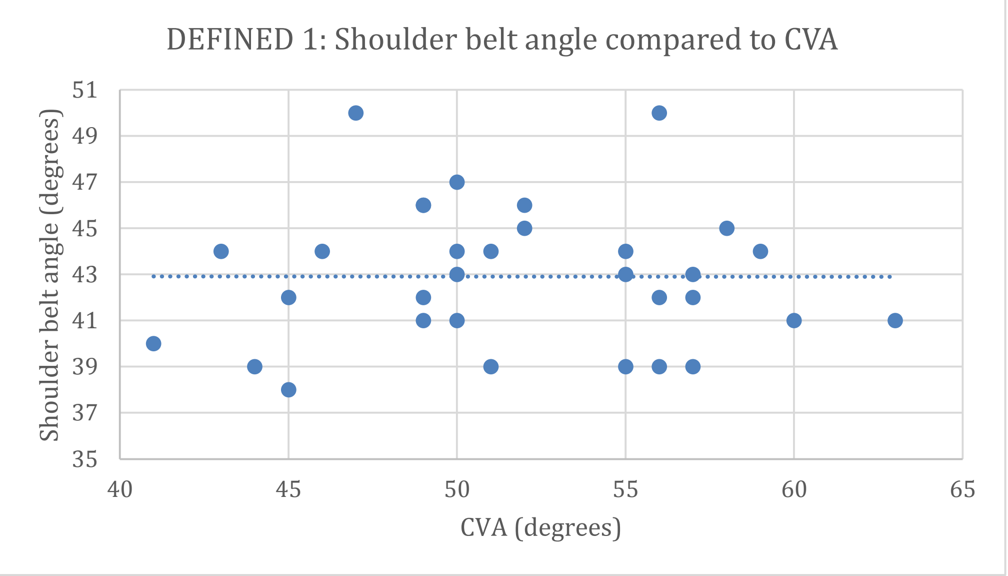


Figure 6.38 – Shoulder belt angle compared to CVA, in the defined seat position 1.

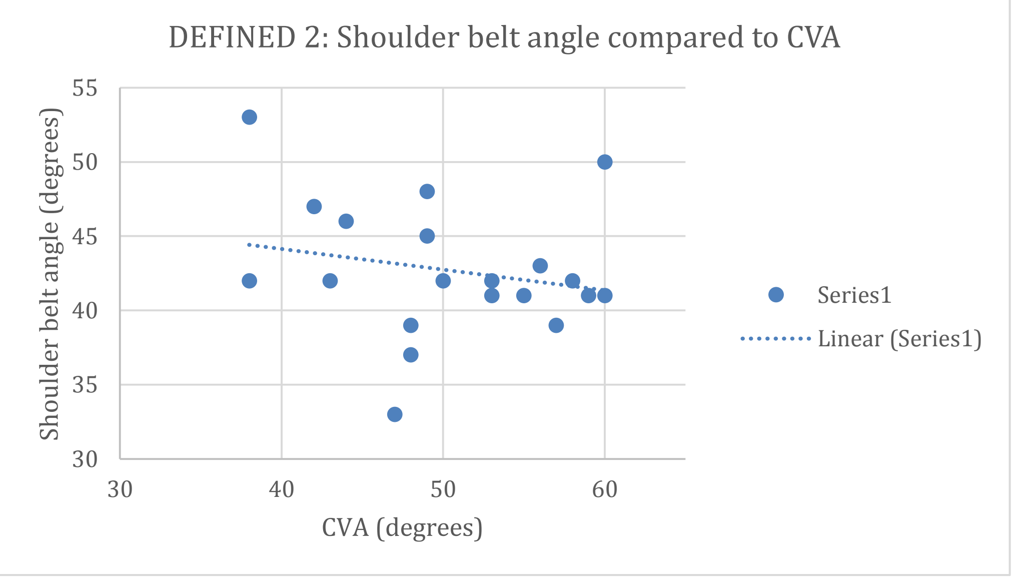


Figure 6.39 – Shoulder belt angle compared to CVA, in the defined seat position 2.

6.2.5 Shoulder belt distance to suprasternal notch

The shoulder belt distance to suprasternal notch was compared between genders and to Age, BMI, stature, waist circumference and CVA. The average distance from suprasternal notch to the upper edge of the shoulder belt was, in the defined seat position 1, 47 mm among females and 65 mm among males. In the defined seat position 2, the average distance was 59 mm among females and 63 mm among males.

The results show that the distance from the suprasternal notch to the upper edge of the shoulder belt was greater among males than females. The findings also indicate that higher age, BMI and waist circumference leads to slightly reduced shoulder belt distance to suprasternal notch. Furthermore, the findings suggest that increased stature leads to increased shoulder belt distance to suprasternal notch.

Age

Regarding shoulder belt distance to suprasternal notch compared to age, the distance was found to decrease when age increase for both genders in the defined seat position 1. This decrease was found slightly more prominent among the male participants (figure 6.40). However, in the defined seat position 2, this trend was not found (figure 6.41).

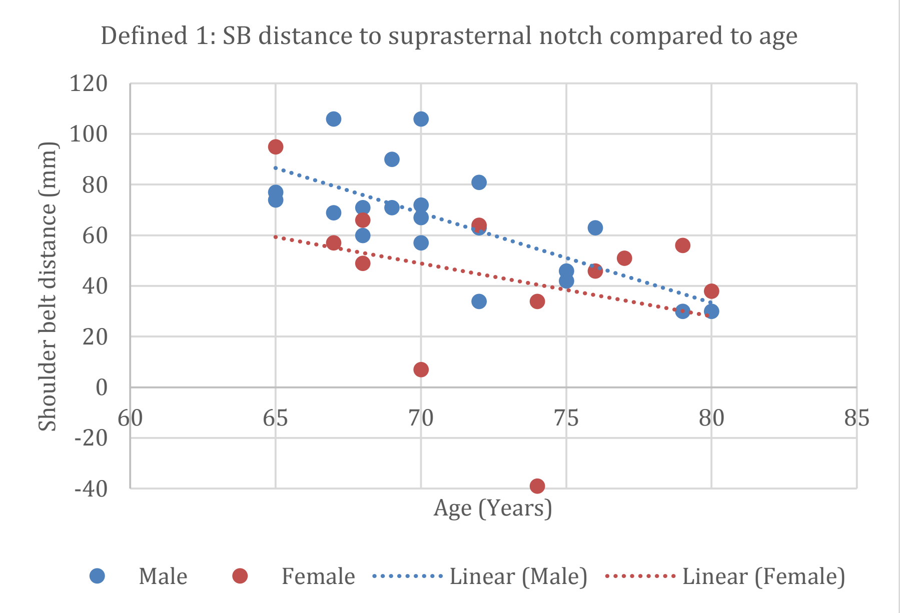


Figure 6.40 - Comparing shoulder belt distance and age in the defined position 1.

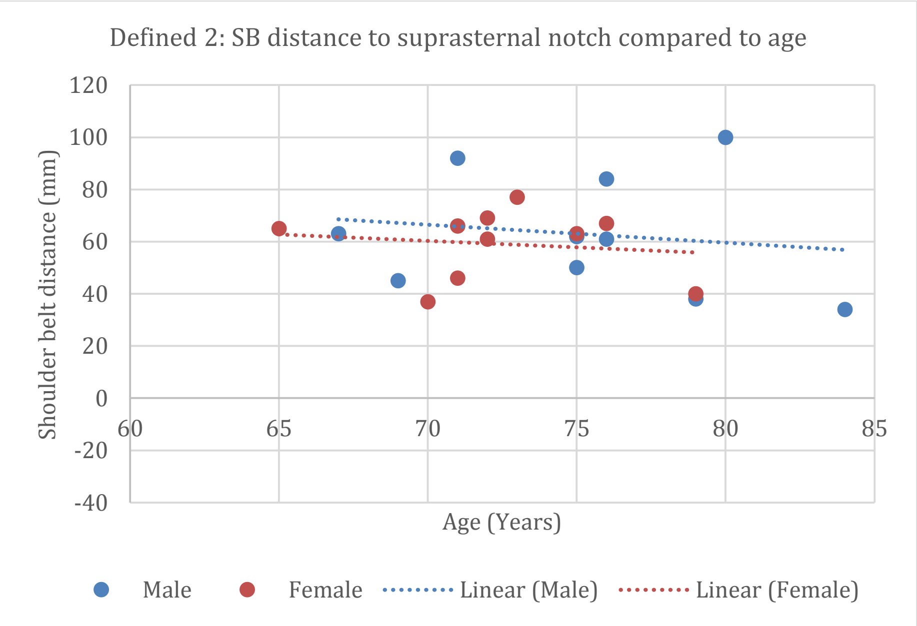


Figure 6.41 - Comparing shoulder belt distance and age in the defined position 2.

BMI

When comparing BMI to shoulder belt distance to suprasternal notch, the distance was found to decrease when the BMI increase for both genders in the defined seat position 1. This decrease was found more prominent among the female participants (figure 6.42). In the defined seat position 2, this trend was not found (figure 6.43).

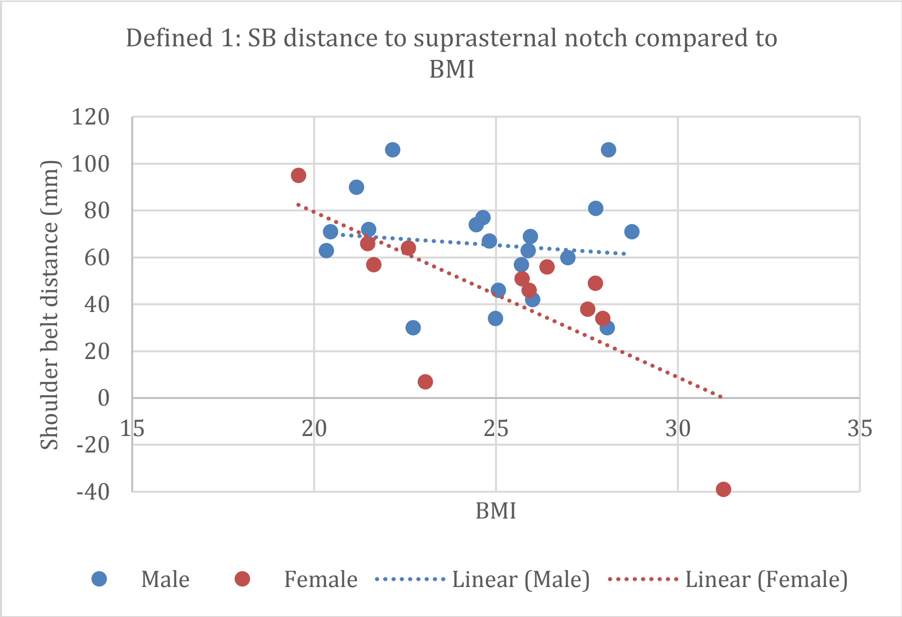


Figure 6.42 - Comparing shoulder belt distance and BMI in the defined position 1.

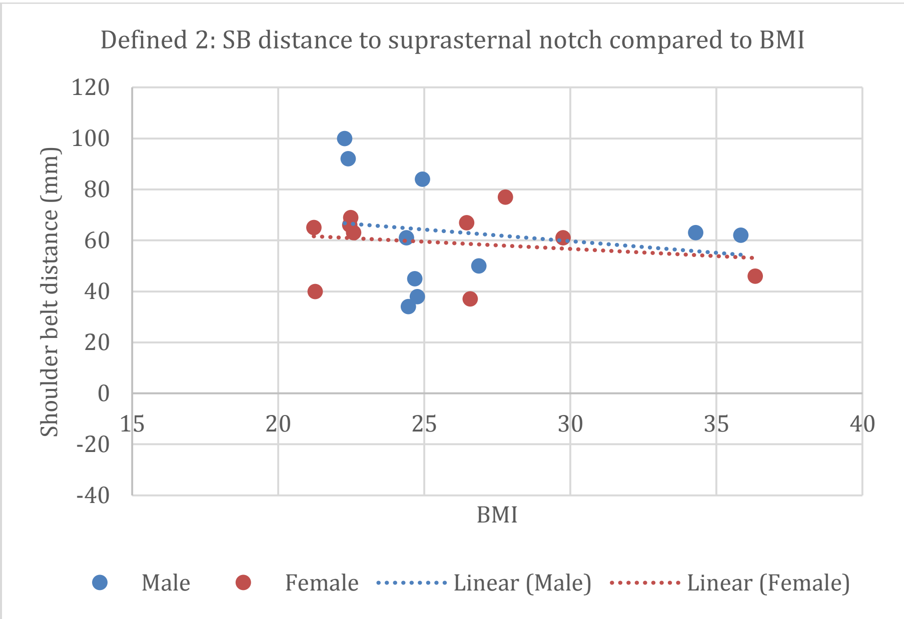


Figure 6.43 - Comparing shoulder belt distance and BMI in the defined position 2.

Stature

Regarding shoulder belt distance to suprasternal notch compared to stature, the distance was found to increase when participant stature increases for both genders in the defined seat position 1. However, this increase was found slightly more prominent among the female participants (figure 6.44). In the defined seat position 2, this trend was not as prominent (figure 6.45).

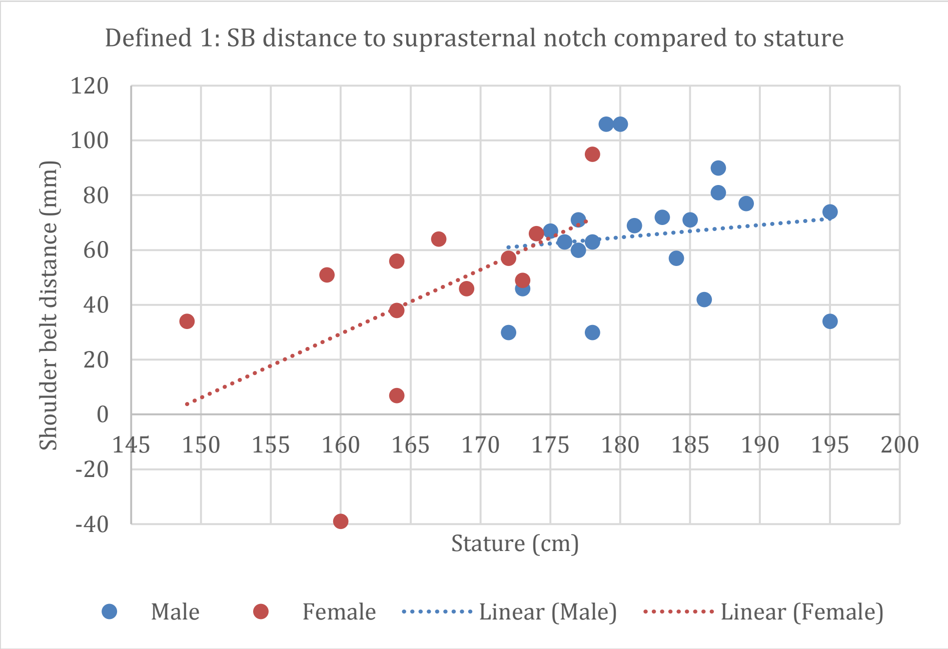


Figure 6.44 - Comparing shoulder belt distance and stature in the defined position 1.

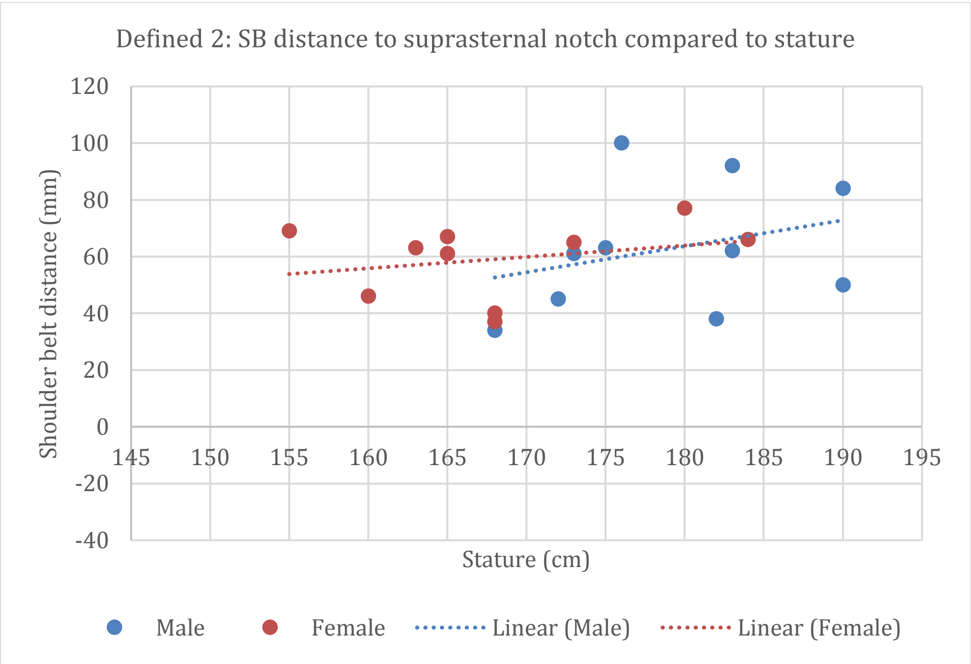


Figure 6.45 - Comparing shoulder belt distance and stature in the defined position 2.

Waist circumference

When comparing shoulder belt distance to suprasternal notch compared to waist circumference, it was found that the distance decrease when the waist circumference increases for both genders in the defined seat position 1. This trend was found slightly more prominent among the female participants (figure 6.46). In the defined seat position 2, a similar trend was found, however slightly more prominent for the male participants (figure 6.47).

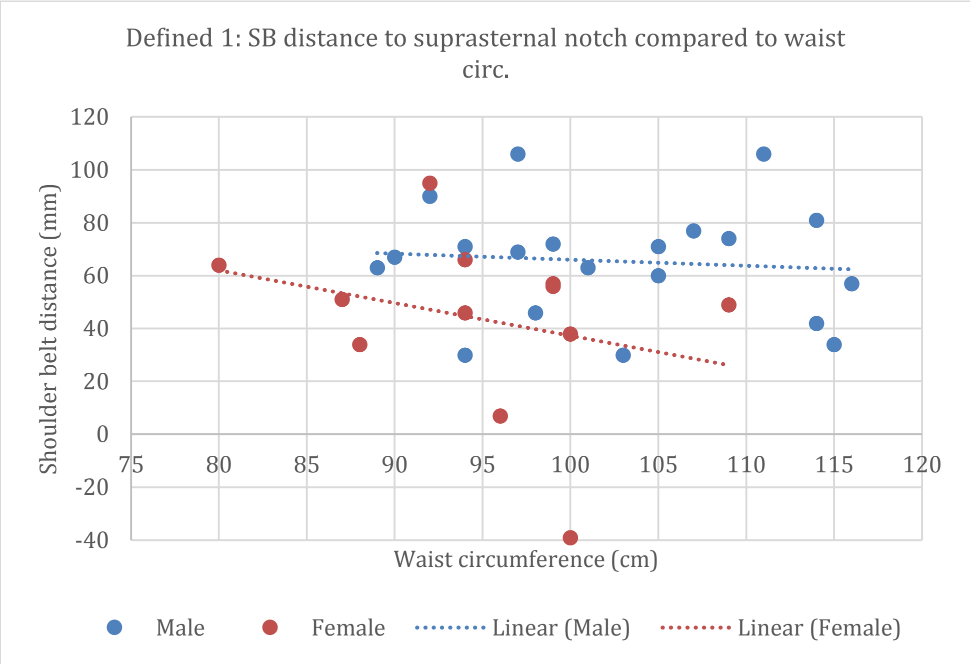


Figure 6.46 - Comparing shoulder belt distance and waist circumference in the defined position 1.

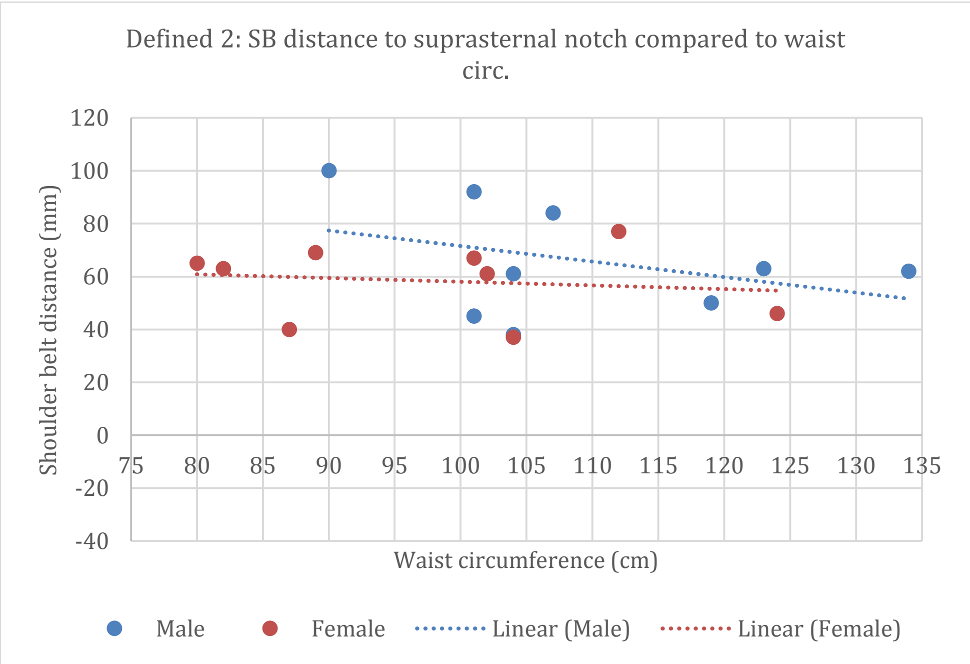


Figure 6.47 - Comparing shoulder belt distance and waist circumference in the defined position 2.

Craniovertebral angle

The craniovertebral angle (CVA) was compared to the distance from the suprasternal notch to the upper edge of the shoulder belt. This was done for both the defined seat position 1 and 2. The shoulder belt distance to suprasternal notch was found to increase with increasing CVA for both genders in the defined seat position 1 (figure 6.48). In the defined seat position 2, the same trend was found for the male participants. However, the opposite was found for the female participants (figure 6.49). Since a lesser CVA indicates a more forward head posture which is associated with thoracic kyphosis, the findings indicate that a more kyphotic posture reduce the distance from the suprasternal notch to the upper edge of the shoulder belt.

Because of the result in the defined seat position 2, this is more likely the case among the male participants than among the female.

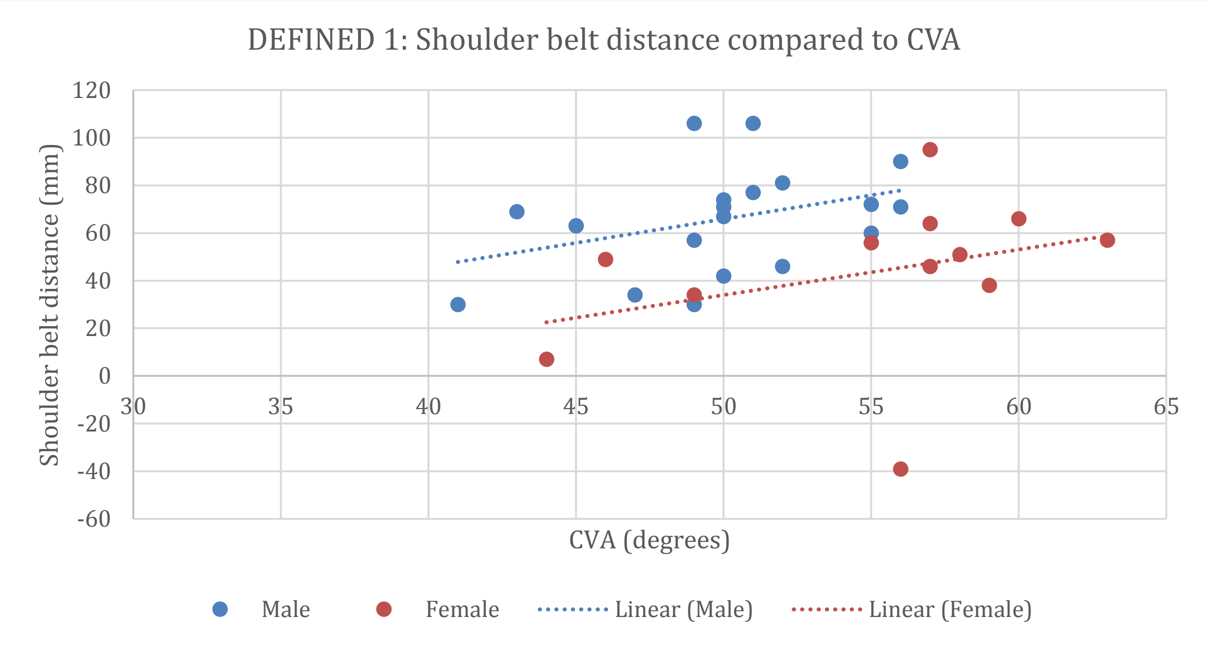


Figure 6.48 - Comparing shoulder belt distance and CVA in the defined position 1.

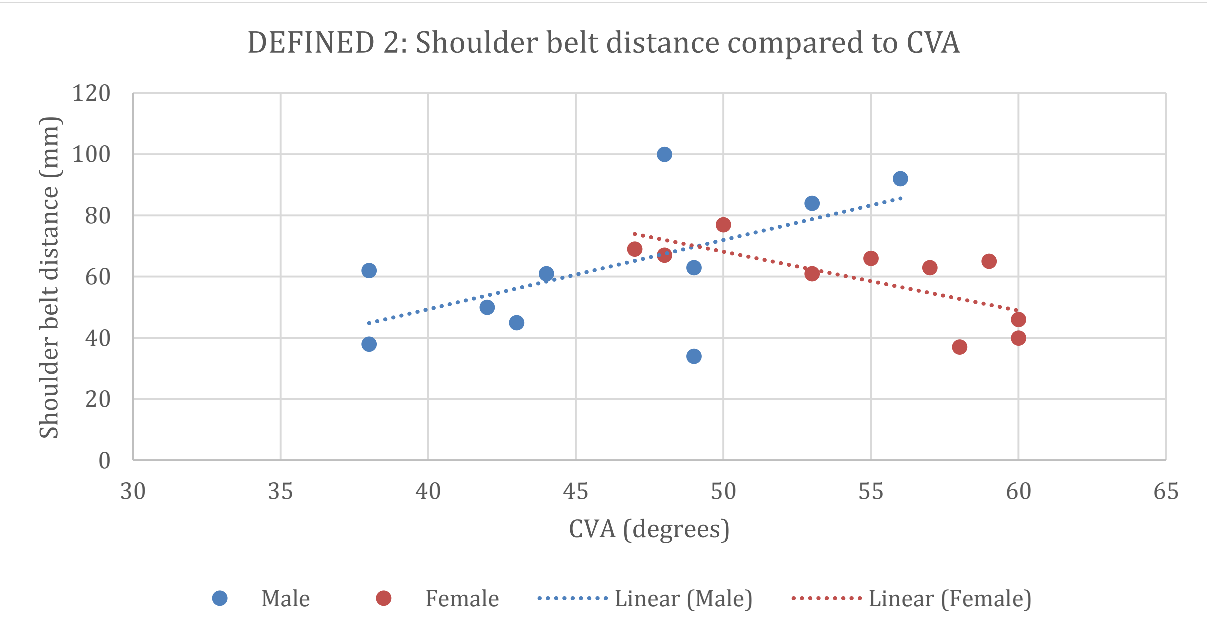


Figure 6.49 - Comparing shoulder belt distance and CVA in the defined position 2.

6.2.6 Summary of results: Factors influencing shoulder belt fit

The results presented below are based on the findings among the participants at the exhibition.

Shoulder belt position on shoulder

- The male participants more commonly had the shoulder belt positioned across the tip of the shoulder than the females and the female participants more commonly had the shoulder belt positioned in contact or close to the neck than the males in the defined seat position 1. In the defined seat position 2, no difference was found between genders.

- In the defined seat position 1, the result shows that a shoulder belt positioned across the tip of the shoulder was most common within the overweight BMI category among the male participants. However, a shoulder belt positioned over the mid portion of the shoulder or in contact/close to the neck, do not seem to be affected by BMI in neither the defined seat position 1 or 2.
- When comparing the shoulder belt position on the shoulder to waist and hip circumference, no trend was found. This was the case for both defined seat positions. This suggest that the shoulder belt position on the shoulder is not largely influenced by waist or hip circumference.
- When comparing the shoulder belt position on the shoulder to stature, the result shows that no participants below 170 cm in stature demonstrate a shoulder belt positioned across the tip of the shoulder. The result also shows that no participant outside the range 160 cm to 169 cm in stature demonstrate a shoulder belt positioned in contact or close to the neck.

Shoulder belt contact from chest to shoulder

- The findings show that more male than female participants demonstrate shoulder belt contact from chest to shoulder in the defined seat position 1. This was not found in the defined seat position 2.
- The findings indicate that BMI do not influence the shoulder belt contact from chest to shoulder.

Shoulder belt position in relation to the abdomen

- The results show a trend that males more commonly have the shoulder belt positioned higher on the abdomen than females.
- The findings show that those with greater BMI are more likely to have the shoulder belt positioned higher on the abdomen.
- The findings show that those with a higher waist and hip circumference are more likely to have the shoulder belt positioned higher on the abdomen.
- No trend was found regarding stature and shoulder belt position in relation to abdomen.

Shoulder belt angle

- The findings indicate that increased BMI leads to increased shoulder belt angle for both genders.
- The findings indicate that increased waist circumference leads to increased shoulder belt angle for both genders.
- Shoulder belt angle compared to stature indicate a difference between the male and female participants in the defined seat position 1, where the shoulder belt angle increases as stature increases among the male participants and decreases as stature increases among the female participants.
- The findings indicate a trend that the shoulder belt angle increase with lower CVA, in the defined seat position 2. However, not in the defined seat position 1.

Shoulder belt distance to suprasternal notch

- The results show that the distance from the suprasternal notch to the upper edge of the shoulder belt was greater among males than females.
- The findings indicate that higher age, BMI and waist circumference leads to slightly reduced shoulder belt distance to suprasternal notch.
- The findings suggest that increased stature leads to increased shoulder belt distance to suprasternal notch.
- Regarding shoulder belt distance to suprasternal notch compared to age, the distance was found to decrease when age increase for both genders in the defined seat position 1. This decrease was found slightly more prominent among the male participants. However, in the defined seat position 2, this trend was not found.
- The findings indicate that a more forward head posture reduces the distance from the suprasternal notch to the upper edge of the shoulder belt. Because of the result in the defined seat position 2, this is more likely the case among the male participants than among the female.

6.3 Lap belt fit

Among the 55 participants in the user study at the exhibition the lap belt fit was judged based on “3.4.2 Defining belt fit parameters”. Since the two defined seat positions only differed in the shoulder belt height adjustment and since the three participants which accidently had the wrong shoulder belt height adjustment only affected the shoulder belt fit analysis, all 55 participants could be analyzed together for the lap belt analysis. Thus, the lap belt fit was analyzed in one defined seat position and one chosen seat position.

6.3.1 Lap belt contact with upper thigh and position on abdomen

Figure 6.50 illustrates an example of two cases when the lap belt was judged in contact with upper thigh and lower on the abdomen and the opposite.

Figure 6.50 – Pictures shows examples of two cases and the assessments of lap belt fit.

Defined seat position

Figure 6.51, describes, in percentage, how many of the participants that, in the defined seat position, had the lap belt in contact with upper thigh and lower on the abdomen or the opposite. In the defined seat position, 76% (42) of the participants did have the lap belt in contact with upper thigh and lower on the abdomen. The remaining 24% (13) did not have the lap belt in contact with the upper thigh.

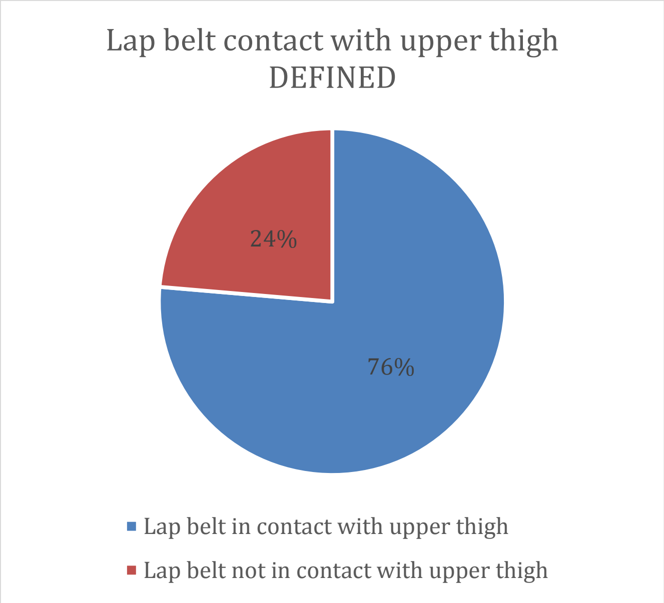


Figure 6.51 - Circle diagram showing in percentage how many of the participants at the exhibition who were judged in contact with upper thigh and lower on the abdomen in the defined position.

Chosen seat position

In the chosen seat position, 80% (44) of the participants did have the lap belt in contact the upper thigh and lower on the abdomen and 20% (11) of the participants did not have the lap belt in contact with the upper thigh or higher on the abdomen (figure 6.52). These findings display that slightly more participants had the lap belt positioned in contact with the upper thigh and lower on the abdomen when seated in the chosen seat position.

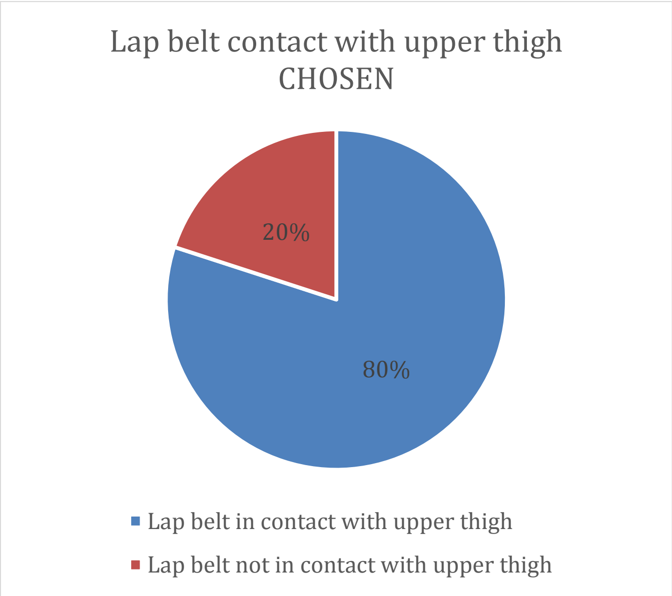


Figure 6.52 - Circle diagram showing in percentage how many of the participants at the exhibition who were judged in contact with upper thigh and lower on the abdomen in the chosen position.

6.3.2 ASIS position in relation to the upper edge of the lap belt

In the chosen seat position, the lap belt fit was also judged based on the location of the participants anterior-superior iliac spines (ASIS) points in relation to the upper edge of the lap belt. The distance from the upper edge of the lap belt to ASIS was physically measured during the user studies and then used for finding out if the participants had their ASIS located over, below or on the upper edge of the lap belt. Figure 6.53, describes, in percentage, how many of the participants that had ASIS located over, below and on the upper edge of the seat belt. In 67% (36) of the participants, ASIS was located over the upper edge of the lap belt. In 18% (10) of the participants, ASIS was located below the upper edge of the seat belt. In 15% (8) of the participants, ASIS was located on the upper edge of the seat belt.

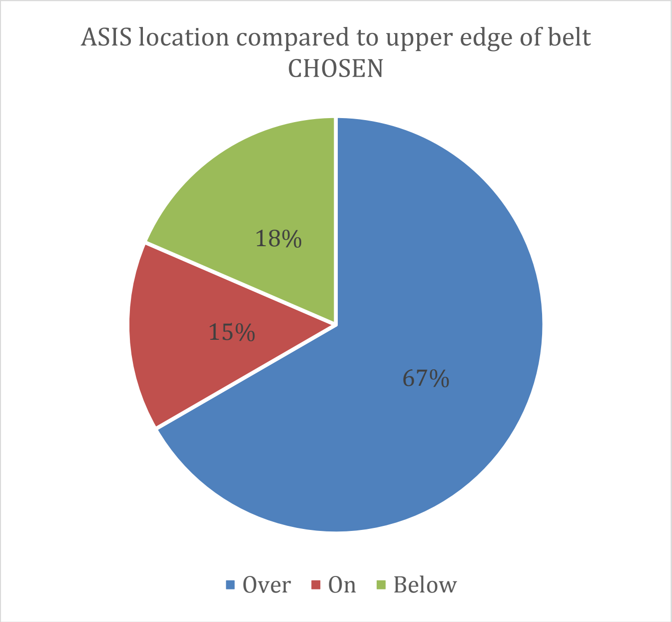


Figure 6.53 - Circle diagram showing in percentage if the ASIS point was located over, on and below the upper edge of the lap belt in the chosen position.

6.3.3 Lap belt angle

The average lap belt angle among the 55 participants was 29 degrees in the defined seat position and 32 degrees in the chosen seat position. Figure 6.54 describe the distribution of the lap belt angle among the participants in both the defined and chosen seat position. The findings display a trend of the elderly participants having a slightly greater lap belt angle when seated in the chosen seat position than in the defined position.

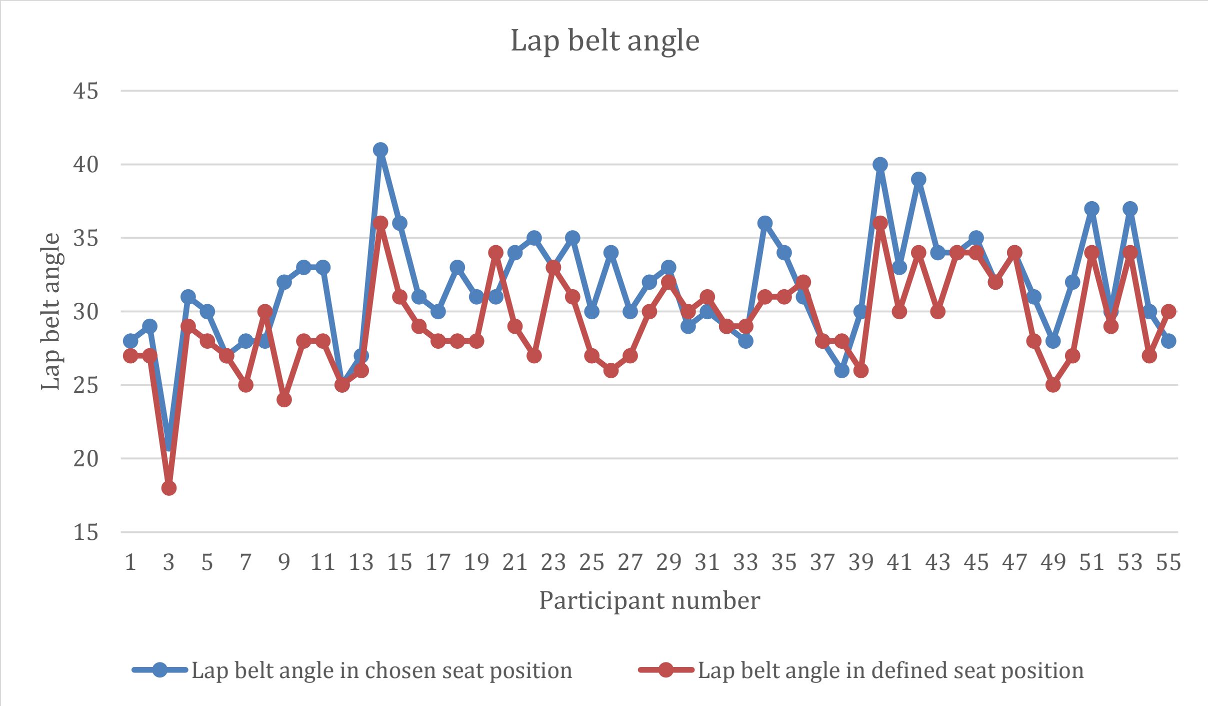


Figure 6.54 - Comparing the lap belt angle between the defined and chosen position.

6.3.4 Summary of results: Lap belt fit

Lap belt contact with upper thigh

- The findings display that slightly more participants had the lap belt positioned in contact with the upper thigh and lower on the abdomen when seated in the chosen seat position.

ASIS position in relation to upper edge of the lap belt

- In 67% (36) of the participants, ASIS was located over the upper edge of the lap belt. In 18% (10) of the participants, ASIS was located below the upper edge of the seat belt. In 15% (8) of the participants, ASIS was located on the upper edge of the seat belt.

Lap belt angle

- The findings display a trend of the elderly participants having a slightly greater lap belt angle when seated in the chosen seat position than in the defined position.

6.4 Factors influencing lap belt fit

The defined position was used to further analyze the lap belt fit compared to gender, BMI, stature, waist and hip circumference.

6.4.1 Lap belt contact to upper thigh and position on abdomen

Gender

The lap belt contact to upper thigh and position on abdomen was compared between genders (figure 6.55). Among the male participants, 91 % (29) had the lap belt in contact with the upper thigh and lower on the abdomen and 9% (3) did not have the lap belt in contact with the upper thigh or higher on the abdomen. Among the female participants, 57% (13), had the lap belt in contact with the upper thigh and 43% (10) did not have the lap belt in contact with the upper thigh or higher on the abdomen. These findings display that lap belt contact to upper thigh and lower on the abdomen was more commonly demonstrated among the male participants than the female participants.

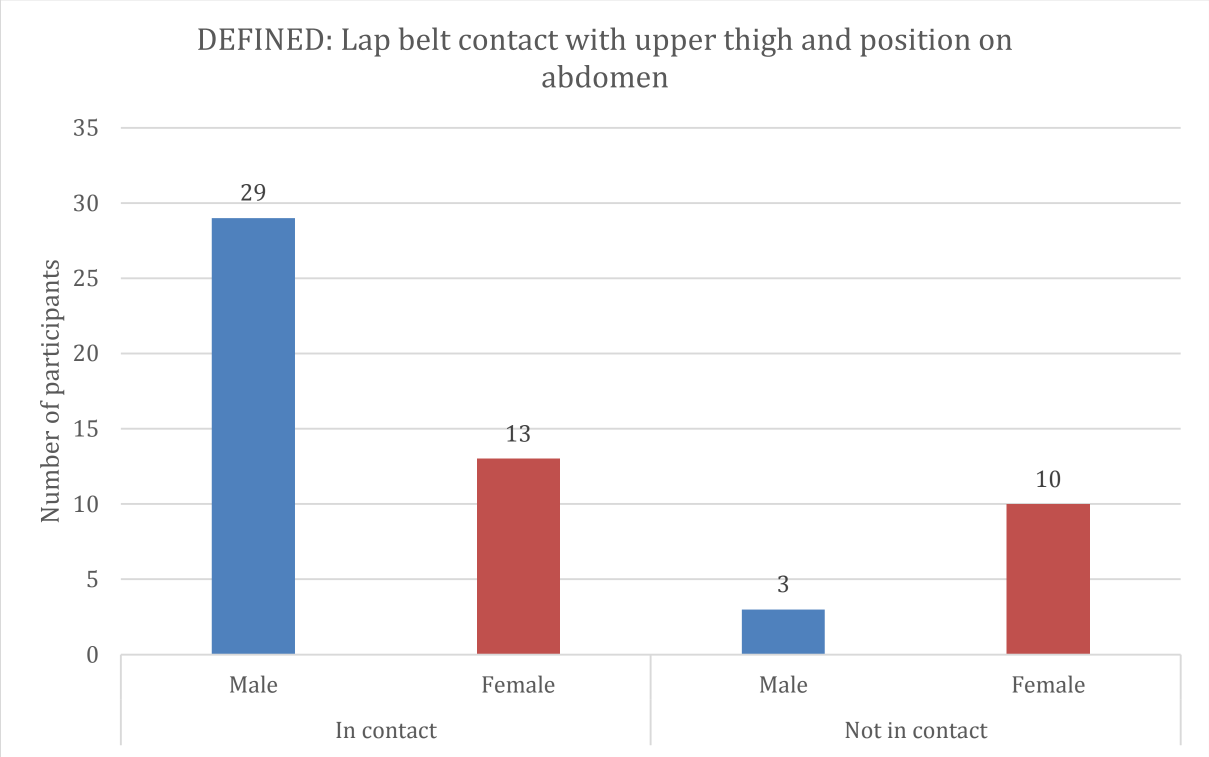


Figure 6.55 - Comparing the number of participants judged in contact with upper thigh and lower on the abdomen with gender in the defined position.

BMI

The lap belt contact to upper thigh was also compared between BMI categories (figure 6.56). Among the female participants, the result shows that lap belt contact to upper thigh and lower on the abdomen was slightly more common within the normal BMI category. Among the male participants, the result does not show any differences in regard to BMI.

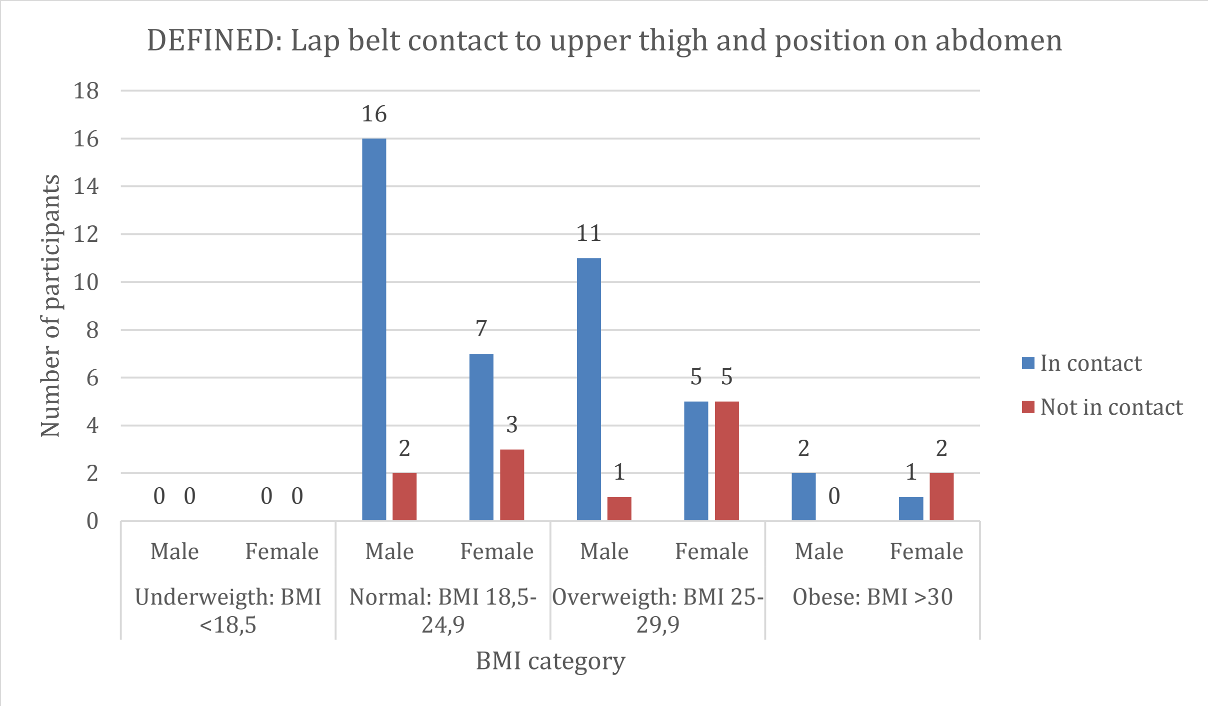


Figure 6.56 - Comparing the number of participants judged in contact with upper thigh and lower on the abdomen with BMI categories in the defined position.

Waist and hip circumference

The lap belt contact to upper thigh was also compared with waist and hip circumference (figure 6.57 & 6.58). No noticeable trend was found in waist or hip circumference influencing lap belt contact to upper thigh. However, for the female participants, slightly more participants had the lap belt not in contact within a higher waist circumference category.

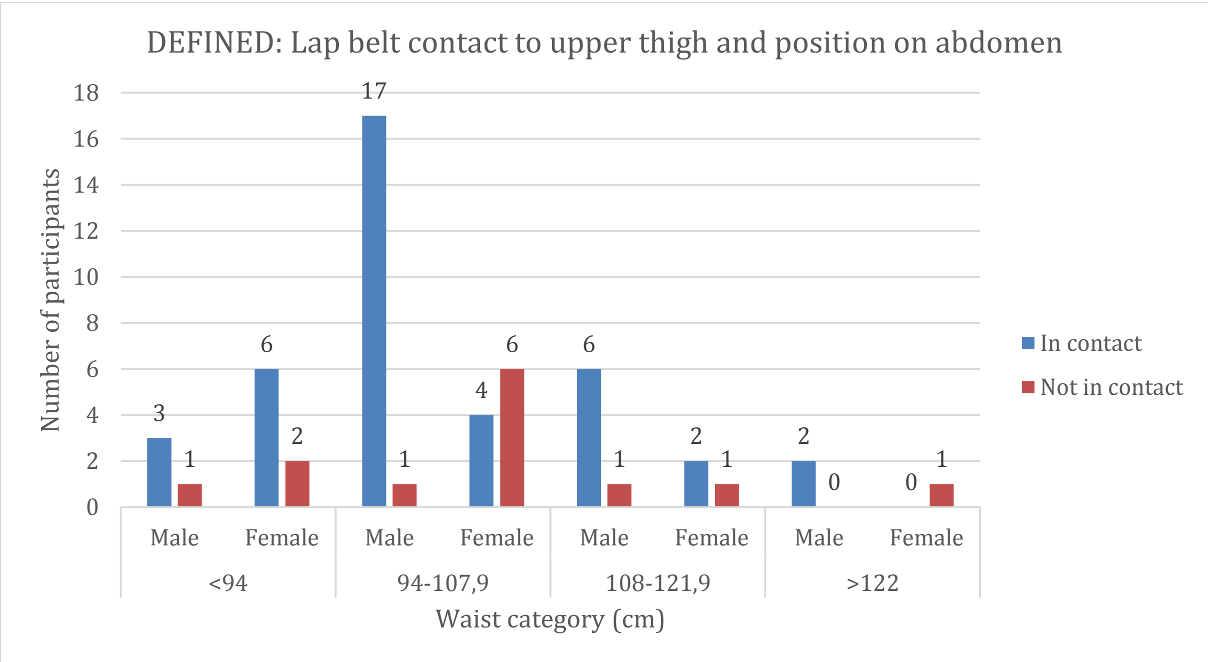


Figure 6.57 - Comparing the number of participants judged in contact with upper thigh and lower on the abdomen with waist circumference categories in the defined position.

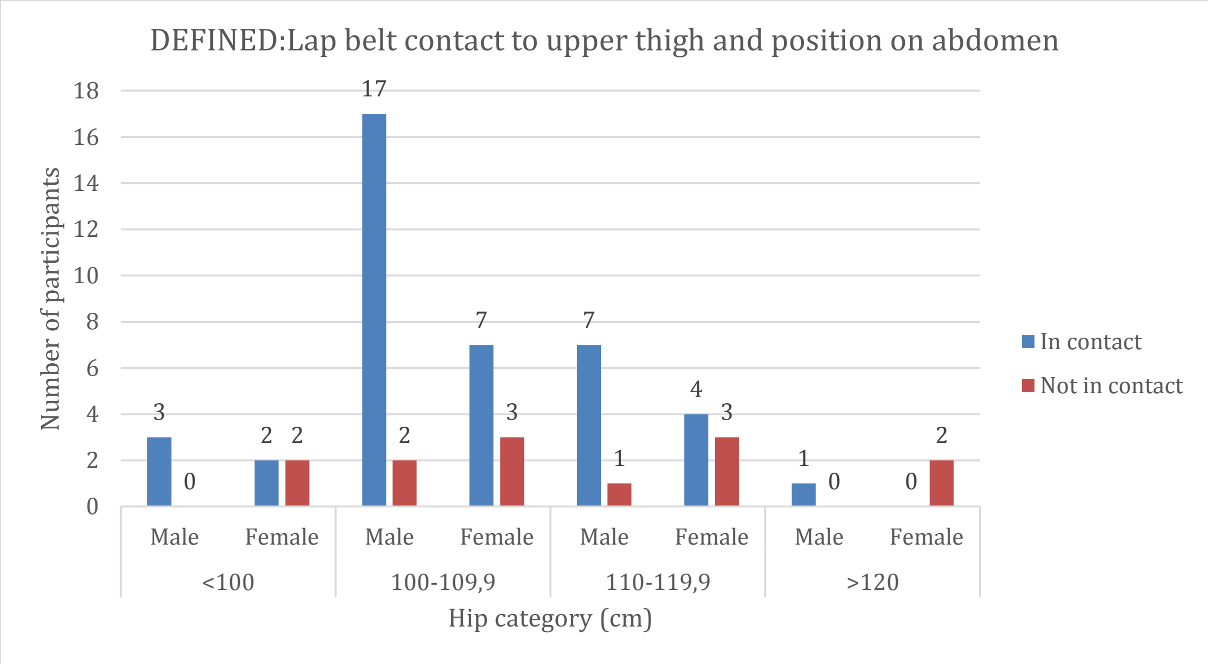


Figure 6.58 – Comparing the number of participants judged in contact with upper thigh and lower on the abdomen with hip circumference categories in the defined position.

6.4.2 Lap belt angle

The lap belt angle was compared between genders and to BMI as well as to waist and hip circumference. No differences in lap belt angle between genders were found. When comparing BMI to lap belt angle, the lap belt angle was found to increase with higher BMI for both genders. This increase was slightly more prominent among the male participants (figure 6.59). A similar result was found for the male participants regarding waist and hip circumference compared to lap belt angle. However, among the female participants, the lap belt angle was not found influenced by waist or hip circumference (figure 6.60 & 6.61).

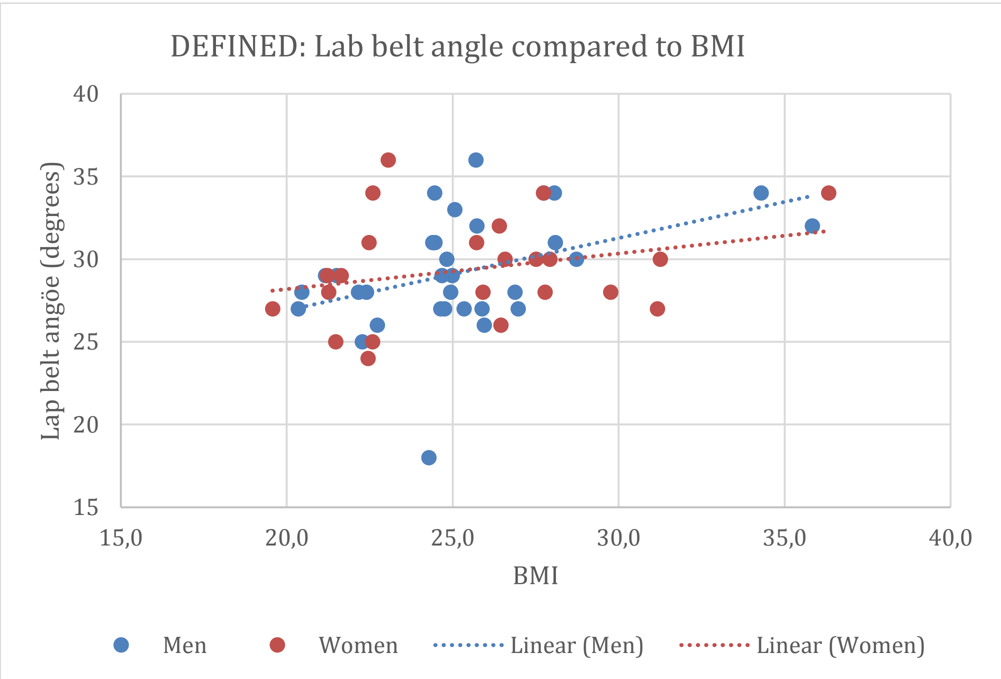


Figure 6.59 - Showing lap belt angle compared to BMI in the defined position.

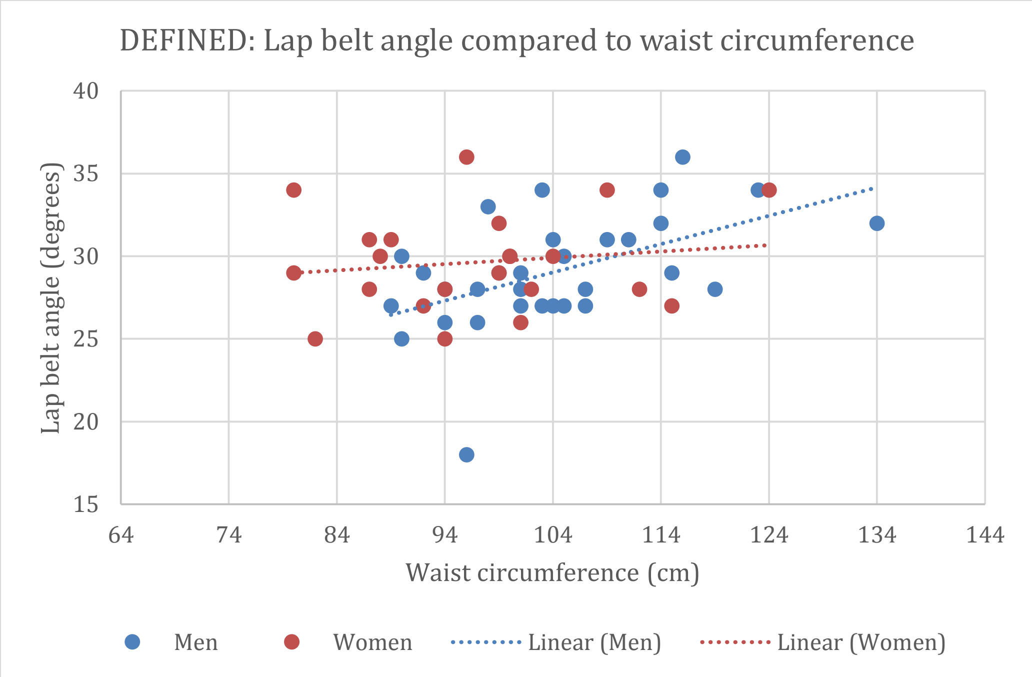


Figure 6.60 - Showing lap belt angle compared to waist circumference in the defined position.

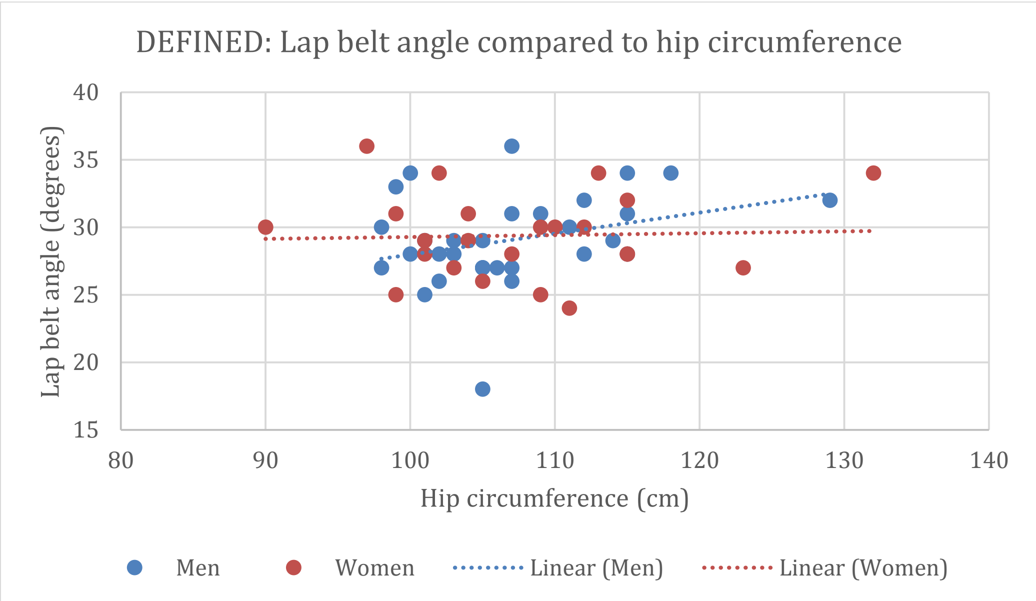


Figure 6.61 - Showing lap belt angle compared to hip circumference in the defined position.

6.4.3 Summary of results: Factors influencing lap belt fit

Lap belt contact with upper thigh

- The findings display that lap belt contact to upper thigh and lower on the abdomen was more commonly demonstrated among the male participants than the female participants.
- Among the female participants, the result shows that lap belt contact to upper thigh and lower on the abdomen was slightly more common among within the normal BMI category. Among the male participants, the result does not show any differences in regard to BMI.

- No noticeable trend was found in waist or hip circumference influencing lap belt contact to upper thigh. However, for the female participants, slightly more participants had the lap belt not in contact within a higher waist circumference category.

Lap belt angle

- No differences in lap belt angle between genders were found.
- When comparing BMI to lap belt angle, the lap belt angle was found to increase with higher BMI for both genders. This increase was slightly more prominent among the male participants.
- A similar result was found for the male participants regarding waist and hip circumference compared to lap belt angle. However, among the female participants, the lap belt angle was not found influenced by waist or hip circumference.

6.5 Overall belt fit and participant awareness

To find out how many of the participants that overall had good belt fit, the participants were scored good or bad on both shoulder and lap belt fit according to Fong et al. (2016). This was done for the participants chosen seat position. To achieve overall good seat belt fit, the participants were required to have both good shoulder and lap seat belt fit.

6.5.1 Overall seat belt fit

In the chosen seat position, 58 % (32) of the participants demonstrated good overall seat belt fit and 42% (23) demonstrated bad overall seat belt fit (figure 6.62).

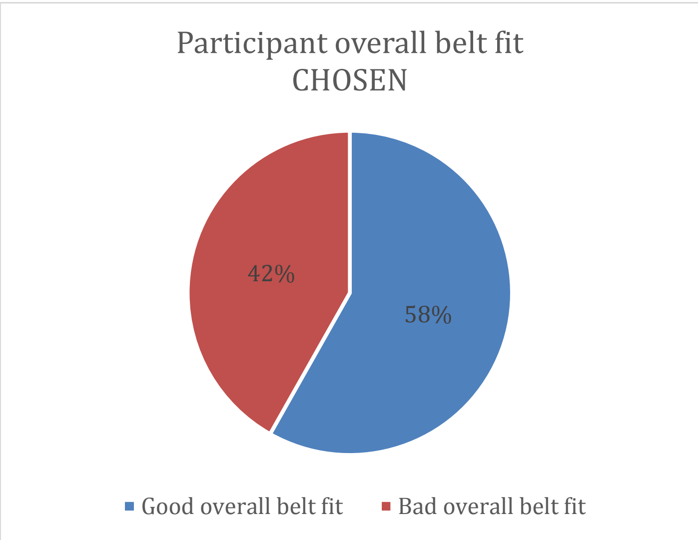


Figure 6.62 - Showing in percentage how many participants who were judged to have good overall belt fit in the chosen position.

6.5.2 Participant assessment of overall belt fit

During the user studies, the participants were asked to assess their own seat belt fit out of a safety perspective, in the chosen seat position. Out of the 42% (23) participants that demonstrated bad overall seat belt fit in the chosen seat position, 74% (17) assessed their seat belt fit as good/safe and 26% (6) assessed their seat belt fit as not safe/bad (figure 6.63). The result indicates that there is low awareness of what good seat belt fit is defined as among the elderly.

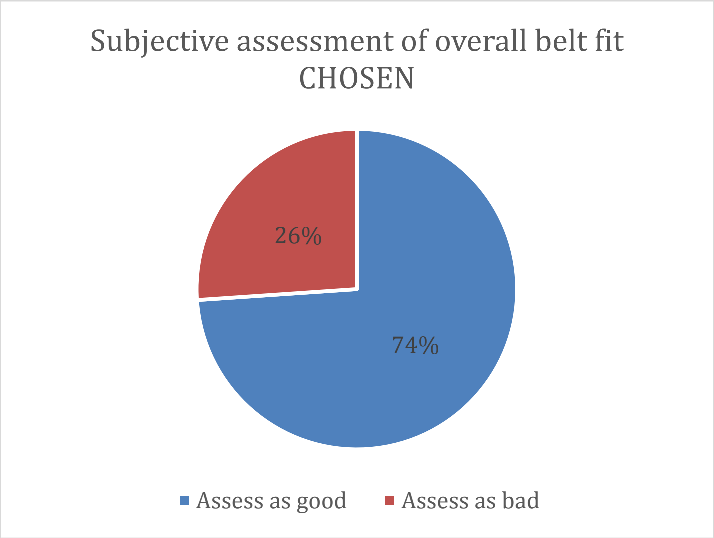


Figure 6.63 - Showing in percentage how many of the participants who was judged bad overall belt fit who assessed their own belt fit good in the chosen position.

6.5.3 Twisted seat belt

Among the 55 participants, 14% (8) demonstrated a twisted seat belt. Out of these 4% (2) demonstrated a twisted shoulder belt and 10% (6) a twisted lap belt. Figure 6.64, display an example of a twisted lap and shoulder belt, identified during the user study at the exhibition. The findings indicate that the elderly, once again, have low awareness of their seat belt fit.

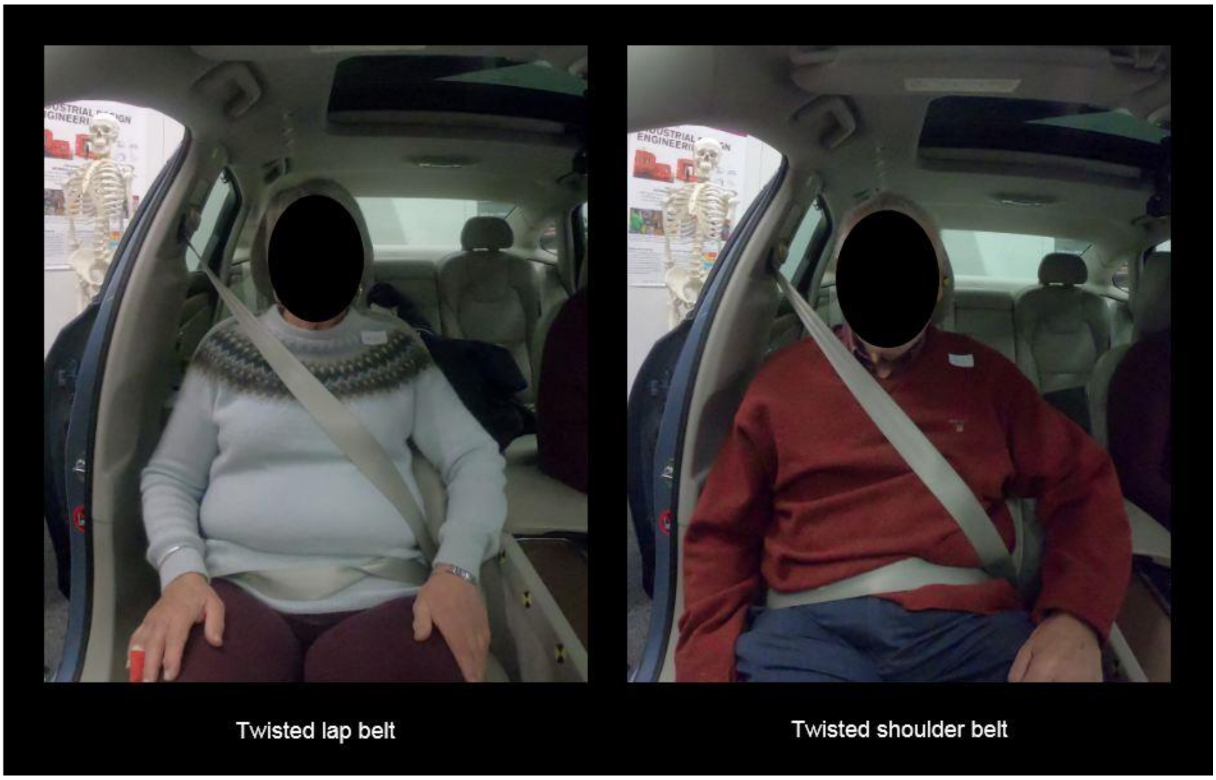


Figure 6.64 - Pictures showing two examples of twisted seat belts at the exhibition.

6.5.4 Seat belt slack

The seat belt slack was measured on all 55 participants. The average slack was 31mm. However, since all participants were asked to tighten the seat belt themselves the result should be considered as overview rather than exact measurements. The distribution of seat belt slack can be seen in figure 6.65.

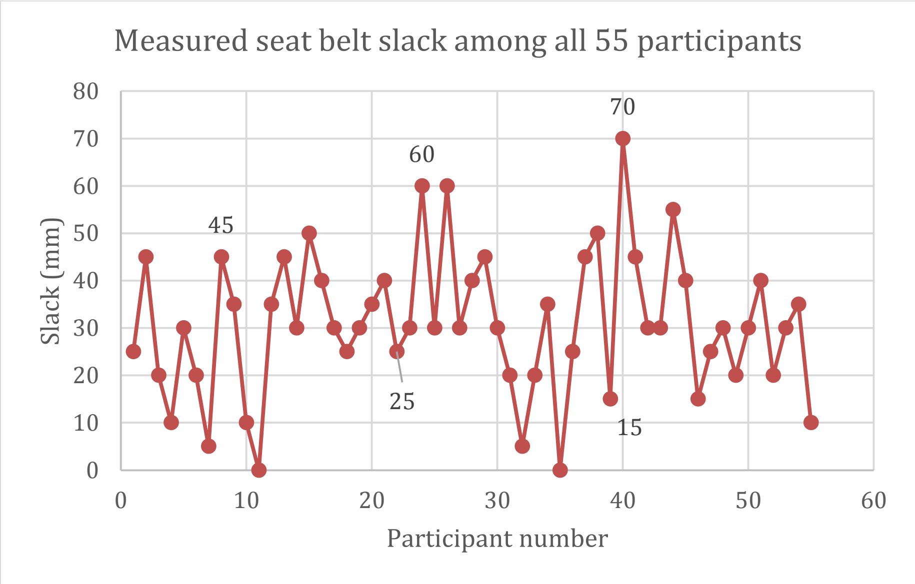


Figure 6.65 - Showing the seat belt slack measured of all participants at the exhibition.

6.5.5 Summary of results: Overall belt fit and participant awareness

Overall belt fit and participant awareness

- 42% (23) demonstrated overall bad belt fit and 58 % (32) demonstrated overall good belt fit.

Assessment of overall belt fit

- Out of the 42% who demonstrated bad overall belt fit, 74% assessed their seat belt fit was good/safe.

Twisted seat belt

- Among the 55 participants, 14% (8) demonstrated a twisted seat belt. Out of these 4% (2) demonstrated a twisted shoulder belt and 10% (6) a twisted lap belt

7. Comparing young and old on belt fit

This chapter describe the findings from the comparative user study, related to belt fit and participant perception of belt fit among the 11 elderly and 11 young participants. This includes findings related to shoulder, lap, and overall seat belt fit. Examples of photographs that were taken of both young and old participants, their body data and the assessment of their seat belt fit can be seen in Appendix 8.

7.1 Shoulder belt fit comparison between old and young

The shoulder belt fit was, as in chapter 6, judged based on where it was positioned on the shoulder of the participant, if it was in contact with the body from the chest to shoulder and on the position it had in relation to the abdomen of the participants. This was done for both the defined seat position 1 and the participants chosen seat position.

7.1.1 Shoulder belt position on shoulder

Defined seat position 1

In the defined seat position 1, 7 (64%) of the old participants had the shoulder belt positioned over the mid portion of the shoulder, 2 (18%) had it positioned in contact with the neck and 2 (18%) had it positioned across the tip of the shoulder (figure 7.1). Among the young participants in the defined seat position 1, 10 (91%) had the shoulder belt positioned over the mid portion of the shoulder and 1 (9%) had it positioned in contact with the neck (figure 7.2).

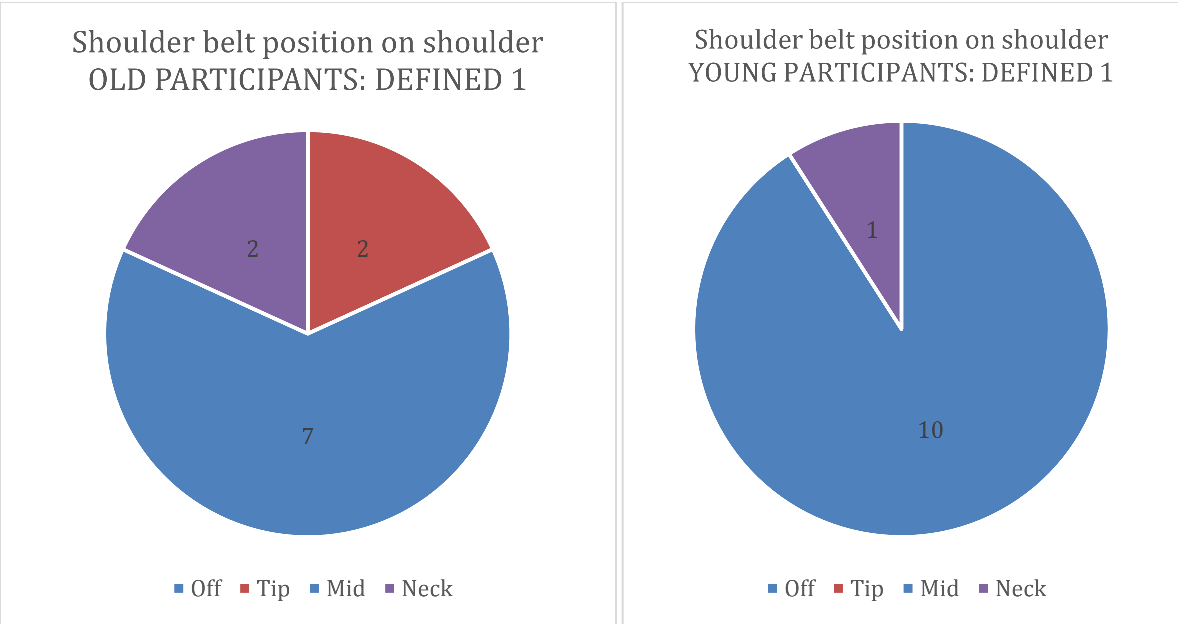


Figure 7.1 and 7.2 - The number of participants in the old and young group judged to have the shoulder belt positioned off, tip, mid and neck in the defined position.

Chosen seat position

In the chosen seat position, 6 (55%) of the elderly had it positioned over the mid portion of the shoulder, 3 (27%) had it positioned in contact with the neck and 2 (18%) had it positioned across the tip of the shoulder (figure 7.3). Among the young participants, 10 (91%) had the shoulder belt positioned over the mid portion of the shoulder and 1 (9%) had it positioned in contact with the neck (figure 7.4).

These findings indicate that the young participants more commonly had the shoulder belt positioned over the mid portion of the shoulder than the old participants. Furthermore, the findings indicate that shoulder belt contact with neck is more common among the old participants.

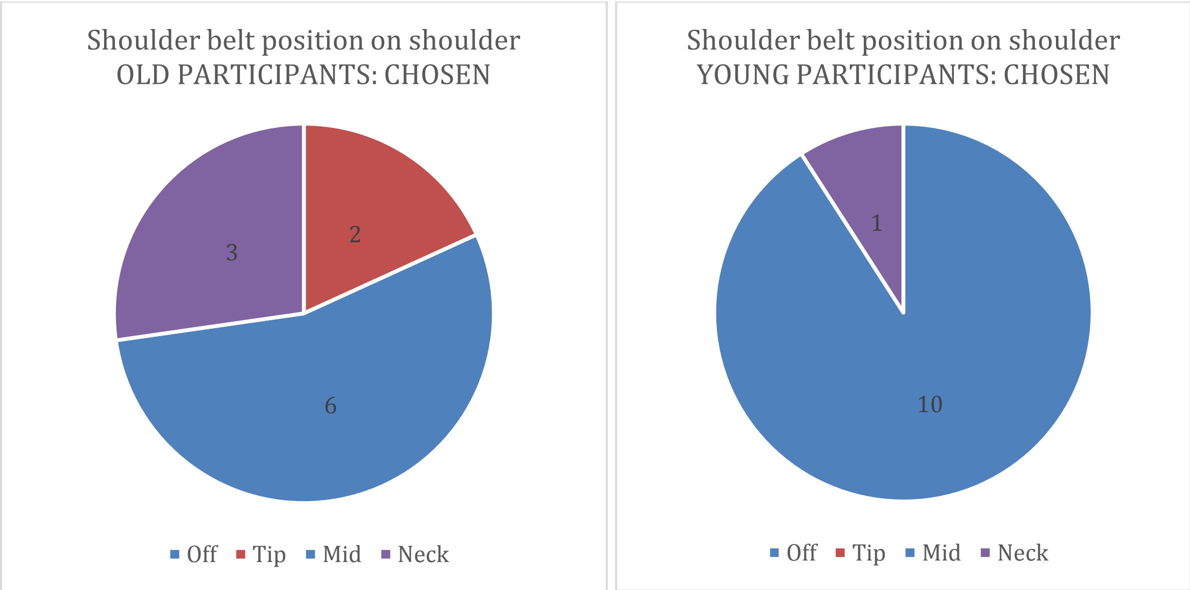


Figure 7.3 and 7.4 - The number of participants in the old and young group judged to have the shoulder belt positioned off, tip, mid and neck in the chosen position.

7.1.2 Shoulder belt contact from chest to shoulder

Regarding if the shoulder belt was in contact from chest to shoulder or not, 9 (91%) of the old participants did have contact and 1 (9%) did not have contact, in both the chosen and defined 1 seat position (figure 7.5). Among the young participants, in both the chosen and defined 1 seat position, 9 (82%) did have contact and 2 (18%), did not have contact (figure 7.6).

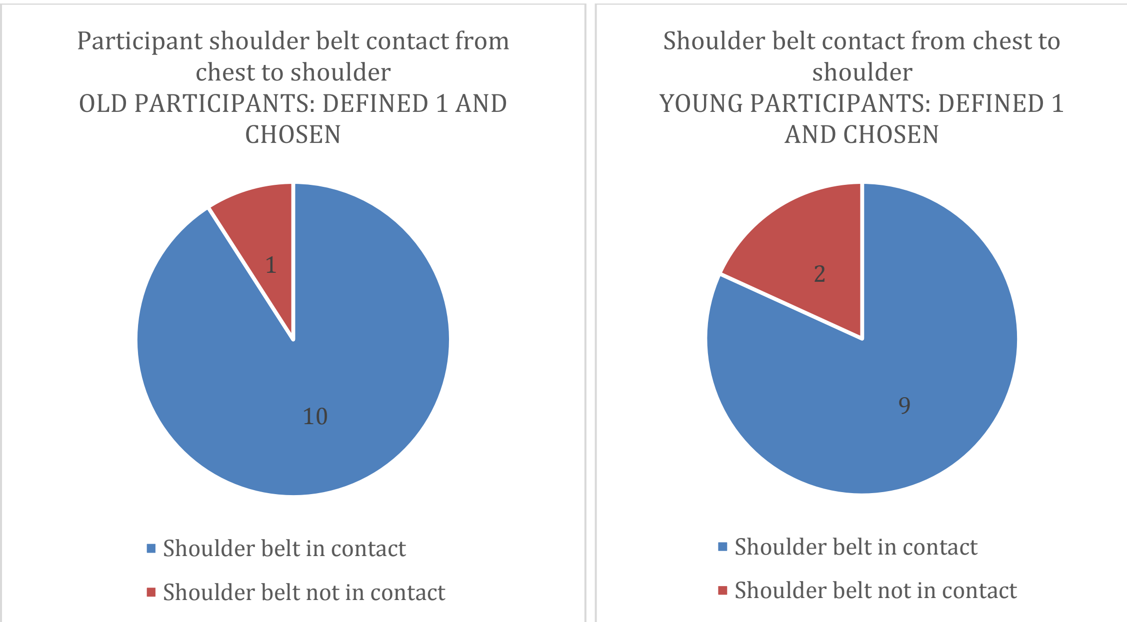
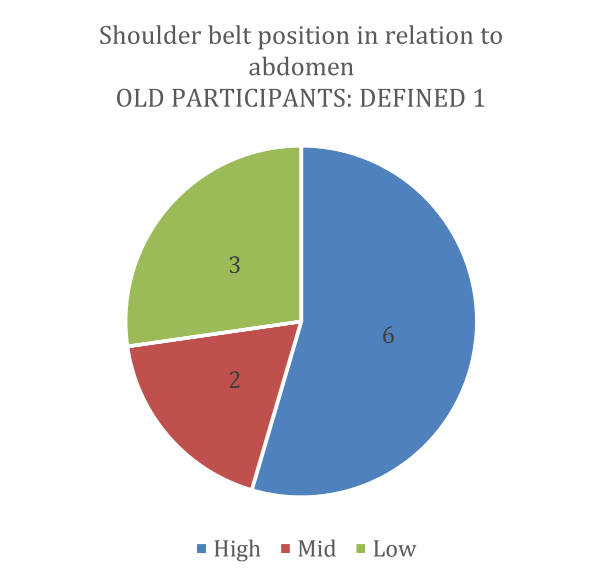


Figure 7.5 and 7.6 - The number of participants in the old and young group judged to have the shoulder belt in contact from chest to shoulder in both the defined and chosen position.

7.1.3 Shoulder belt position in relation to abdomen

Defined seat position 1

In the defined seat position 1, 6 (55%) of the old participants had the shoulder belt positioned high in relation to the abdomen, 3 (27%), had it positioned low in relation to the abdomen and 2 (18%) had it positioned mid in relation to the abdomen (figure 7.7). Among the young participants, 8 (73%) had the shoulder belt positioned low in relation to the abdomen and 3 (27%) had it positioned high in relation to the abdomen, in the defined seat position 1 (figure 7.8).



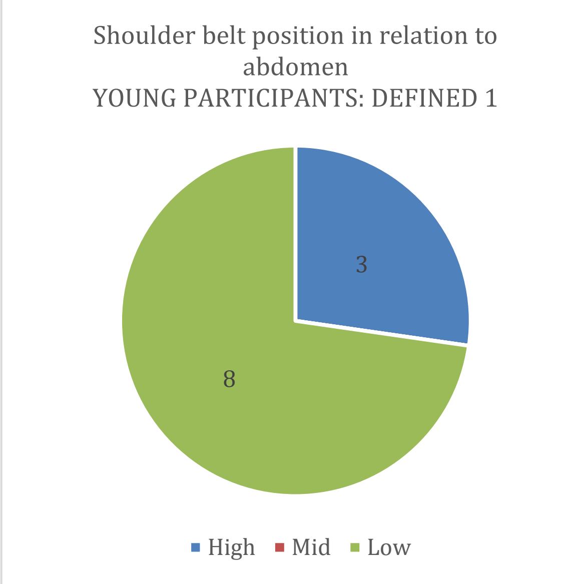


Figure 7.7 and 7.8 - The number of participants in the old and young group judged to have the shoulder belt high, mid and low on the abdomen in the defined position.

Chosen position

In the chosen seat position, 7 (64%) of the old participants had the shoulder belt positioned high in relation to the abdomen, 3 (27%), had it positioned low in relation to the abdomen and 1 (9%) had it positioned mid in relation to the abdomen (figure 7.9). Among the young participants, 8 (73%) had the shoulder belt positioned low in relation to the abdomen and 3 (27%) had it positioned high in relation to the abdomen, in the chosen seat position (figure 7.10).

The findings display that the old participants more commonly had the shoulder belt positioned higher on the abdomen than the young participants. A similar percentage of elderly having the shoulder belt positioned high in relation to the abdomen was found in the user study at the exhibition.

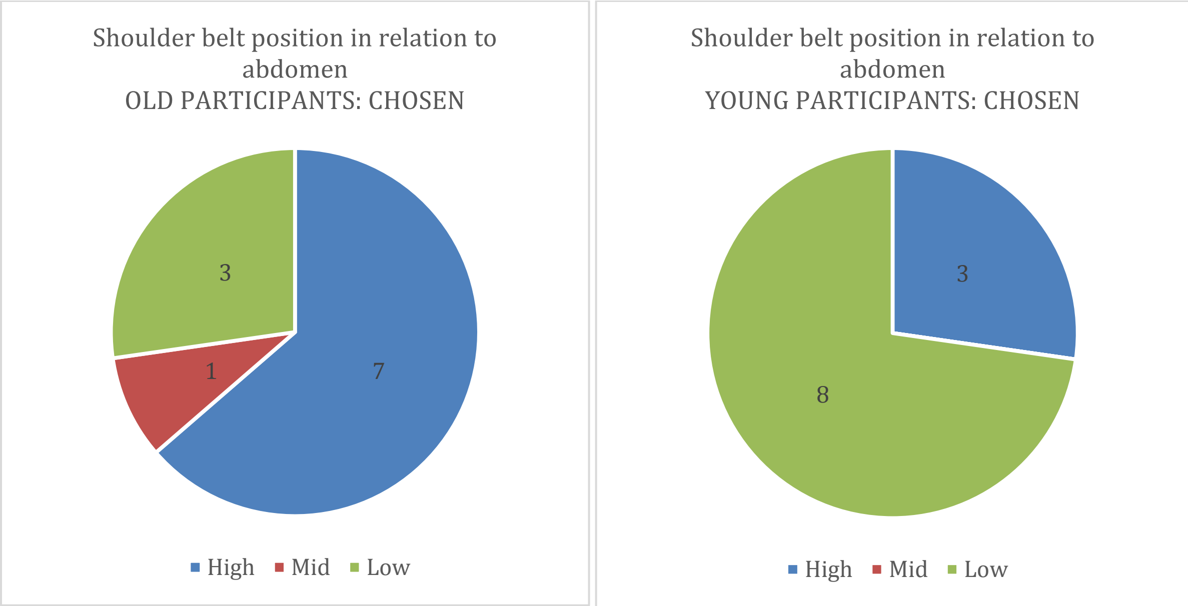
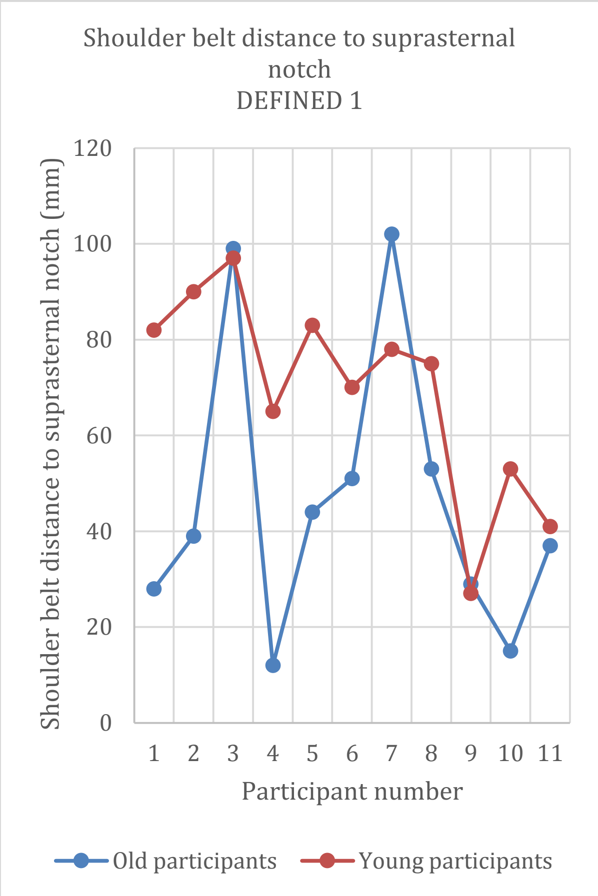


Figure 7.9 and 7.10 - The number of participants in the old and young group judged to have the shoulder belt high, mid and low on the abdomen in the chosen position.

7.1.4 Shoulder belt angle and distance

The shoulder belt vertical distance to the participants suprasternal notch and the angle of the shoulder belt was measured, using the tool ImageJ, as described in "3.4.2 Defining belt fit parameters". This was done for both the defined seat position 1 and for the participants chosen seat position.

The average distance from the suprasternal notch to the upper edge of the shoulder belt among the 11 old participants, was 46mm in the defined seat position 1, and 45mm in the chosen seat position. The average distance from the suprasternal notch to the upper edge of the shoulder belt among the 11 young participants, was 69mm in the defined seat position 1, and 73mm in the chosen seat position. In figure 7.11, the shoulder belt distance of all old and young participants can be seen for the defined seat position 1 and in figure 7.12, the corresponding can be seen for the chosen seat position.



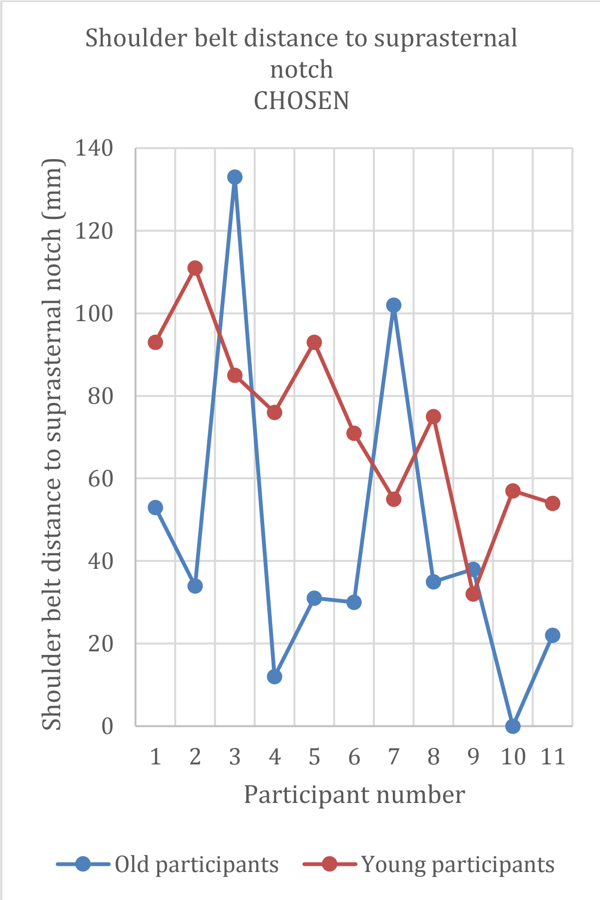
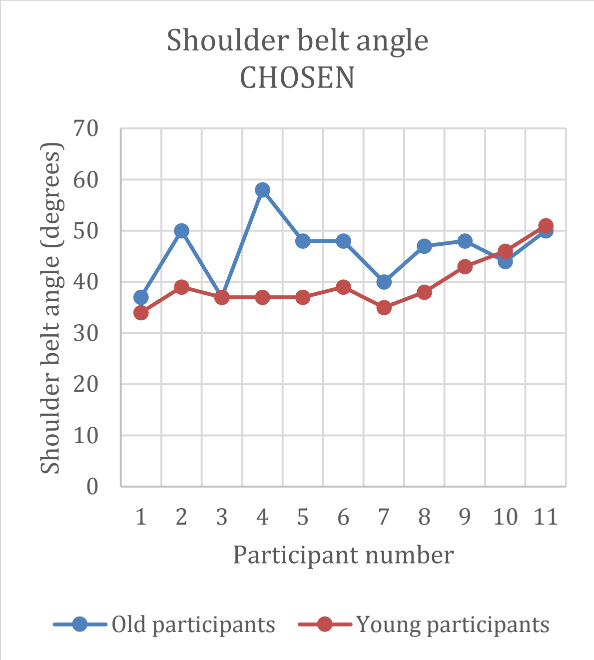


Figure 7.11 and 7.12 - Comparing the shoulder belt distance to the suprasternal notch between young and old in the defined and chosen position.

The average shoulder belt angle among the 11 old participants was 45 degrees in the defined seat position 1 and 46mm in the chosen seat position. The average shoulder belt angle among the 11 young participants was 40 degrees in both the defined 1 and the chosen seat position. In figure 7.13, the shoulder belt angle of all participants can be seen for the defined seat position 1 and in figure 7.14, the corresponding can be seen for the chosen seat position.



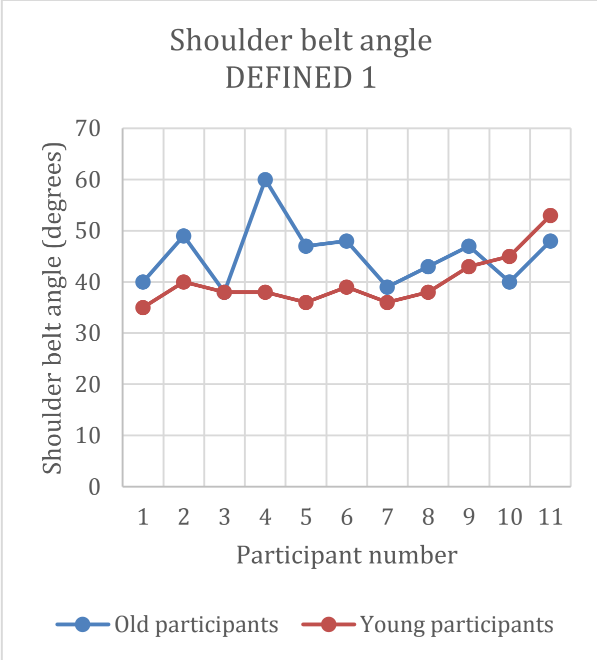


Figure 7.13 and 7.14 - Comparing shoulder belt angle between young and old in the defined and chosen position.

The findings display a trend of the old participants having lower distance from the suprasternal notch to the upper edge of the shoulder belt and a higher shoulder belt angle than the young participants. If comparing the young participants from the comparative user study to the elderly participants at the exhibition, a similar trend can be found regarding the shoulder belt distance from the suprasternal notch to the upper edge of the shoulder belt, where the elderly averaged lower distance.

7.1.5 Summary of result: Shoulder belt fit comparison

Shoulder belt position on shoulder

- When comparing the two groups in the defined position, the result shows that more participants in the young reference group had the belt positioned over the mid portion of the shoulder compared to old. In the old group, 2 had tip and 2, had neck. One of the eleven young had it positioned in contact or close to neck.
- In the chosen position the result looks the same for the young group compared to the old group where the number of participants having the belt positioned in contact with neck increased from two to three.

Shoulder belt contact from chest to shoulder

- In the old group, one participant did not have the shoulder belt in contact from chest to shoulder, compared to two in the young group. The result remained the same in the chosen seat position.

Shoulder belt position in relation to abdomen

- A noticeable difference was found between the two groups regarding shoulder belt position on the abdomen. In the defined seat position, 6 had it positioned high compared to 3 among the young. Furthermore, 2 had mid and 3 had low among the old compared to all the remaining 8 in the young group who had low.

- In the chosen sitting position, the result remained the same for the young compared to the old where one of the mid changed to high.

Shoulder belt angle and distance

- The shoulder belt distance from the suprasternal notch to the upper edge of the seat belt was overall shorter among the old participants compared to the young in both the defined and chosen position.
- The shoulder belt angle was found overall greater in the old group compared to the young and the same result was found in the chosen position.

7.2 Factors influencing shoulder belt fit comparison in defined seat position

In “7.1 Shoulder belt fit comparison”, it was found that the largest differences between the young and old participants were; shoulder belt position in relation to abdomen, shoulder belt angle and shoulder belt distance. These factors were therefore further analyzed in the defined seat position to investigate the reason for the difference.

7.2.1 Shoulder belt position in relation to abdomen

The shoulder belt position in relation to abdomen was compared to BMI categories, waist and hip circumference. The findings show that both for the old and young participants, a shoulder belt positioned high in relation to the abdomen was demonstrated among participants within the overweight and obese BMI category (figure 7.15 & 7.16). The findings show similar trends regarding waist and hip circumference, where participants with greater waist and hip circumference most often demonstrate a shoulder belt positioned high in relation to the abdomen. This trend was similar for both the old and young participants (appendix 9). This suggest that shoulder belt position in relation to abdomen is affected by BMI, waist and hip circumference and not necessarily related to the age-difference between the groups.

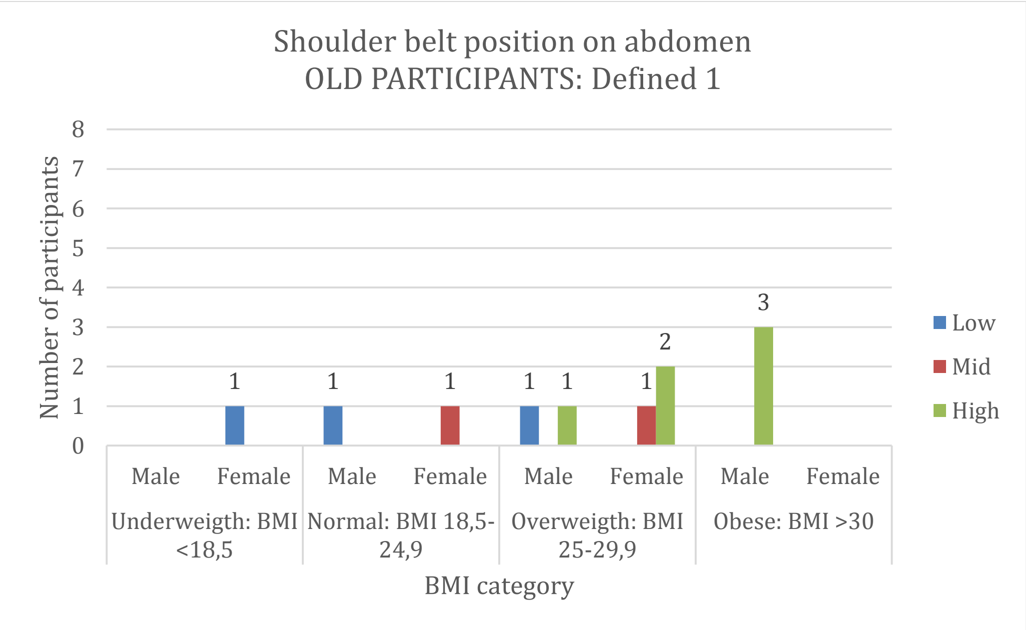


Figure 7.15 - Distribution of old participants judged to have the shoulder belt positioned high, mid and low in BMI categories (Defined position).

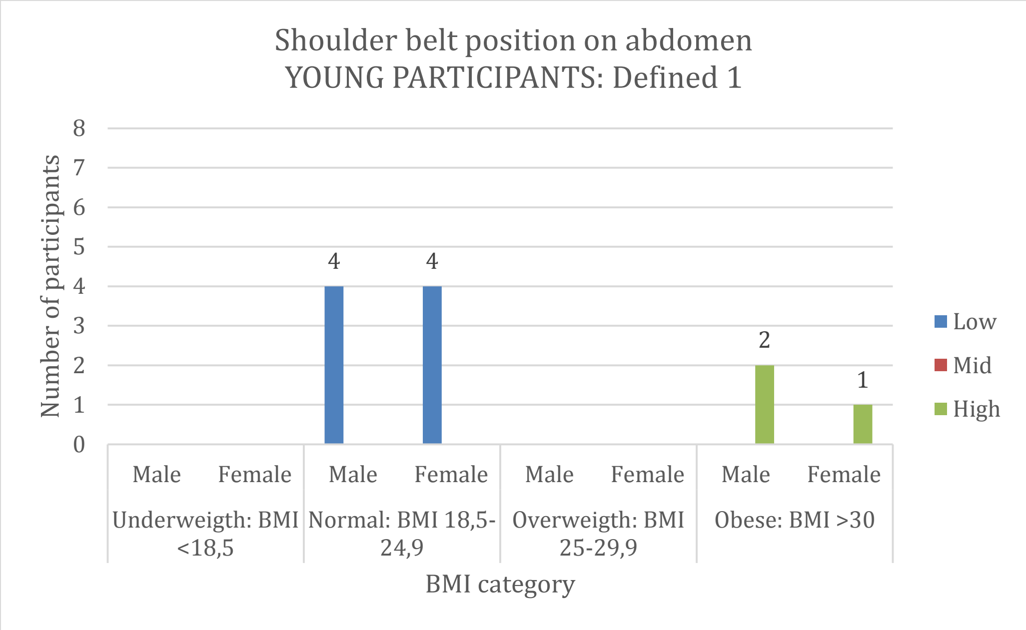


Figure 7.16 - Distribution of young participants judged to have the shoulder belt positioned high, mid and low in BMI categories (Defined position).

7.2.2 Shoulder belt angle and distance

The shoulder belt angle and distance were compared to BMI, stature, waist and hip circumference as well as to the craniovertebral angle (CVA) for both the young and old participants. The findings show the same trends for both the young and old when comparing the shoulder belt angle and distance to BMI, waist and hip circumference. However, when comparing CVA to the shoulder belt angle and distance a difference was found between the old and young participants. The findings indicate that increased CVA increases the shoulder belt distance and decreases the shoulder belt angle among the old participants. The CVA was not found influencing the shoulder belt angle and distance among the young participants (appendix 9).

Shoulder belt angle compared to BMI, waist and hip circumference

The shoulder belt angle was compared to BMI, waist and hip circumference. The shoulder belt angle was found to increase for both the old and young participants with increasing BMI (figure 7.17). Similar trends were found when comparing the shoulder belt angle to both waist and hip circumference (appendix 9).

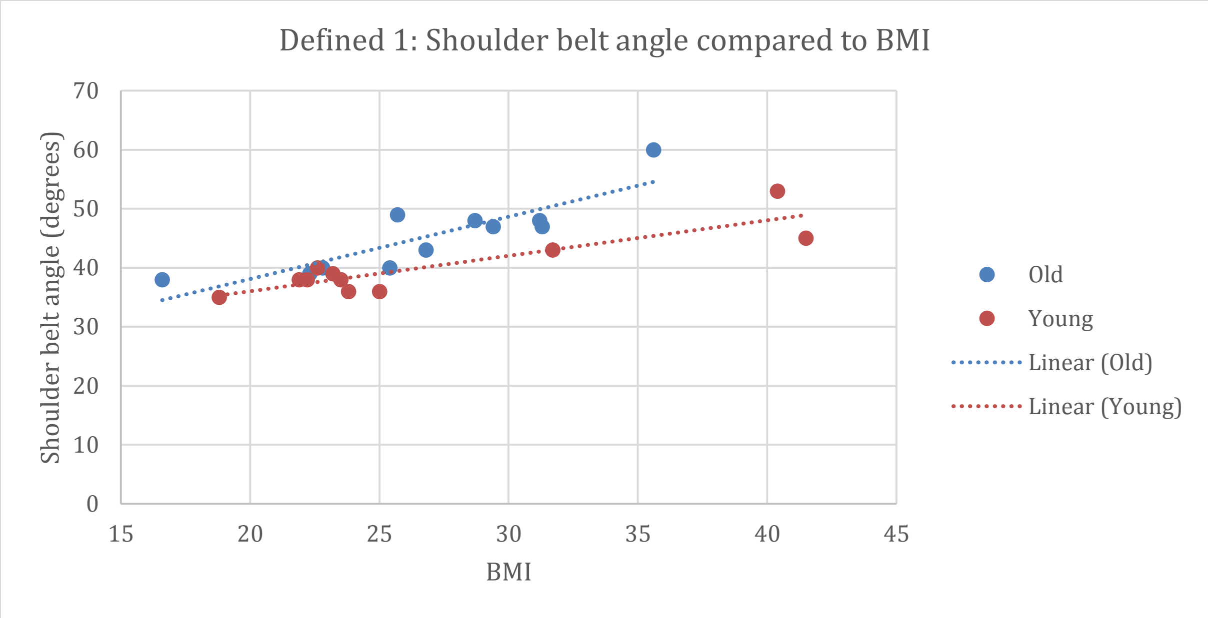


Figure 7.17 - Comparing BMI and shoulder belt angle between young and old in the defined position.

Shoulder belt angle compared to craniovertebral angle

The shoulder belt angle was compared to the CVA among the old and young participants. The results show a difference between the young and old participants. Among the old participants, the shoulder belt angle decreases when CVA increases. Among the young participants, there was no trend in CVA influencing the shoulder belt angle (figure 7.18). Since a lesser CVA indicates a more forward head posture which is associated with thoracic kyphosis, the findings indicate that a more kyphotic posture increases the shoulder belt angle.

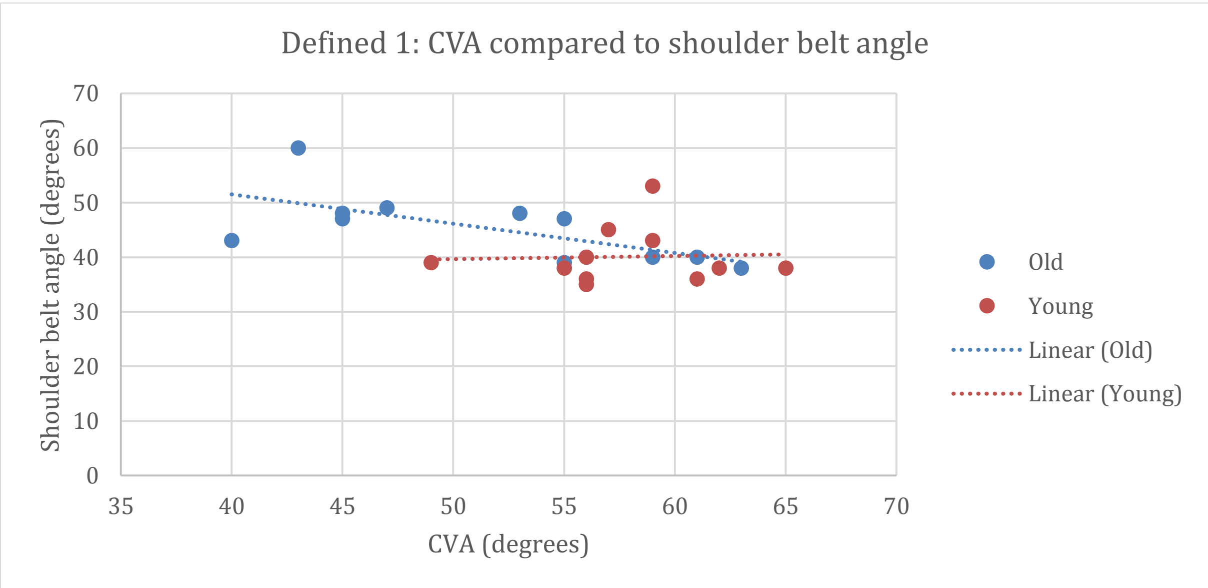


Figure 7.18 - Comparing CVA and shoulder belt angle between young and old in the defined position.

Shoulder belt distance compared to BMI, waist and hip circumference

The shoulder belt distance was compared to BMI. The results show a trend of that the shoulder belt distance decreases when BMI increases for both the old and young participants (figure 7.19). Similar trends were found when comparing both waist and hip circumference to the shoulder belt distance (appendix 9). This suggest that the distance is affected by BMI, waist and hip circumference for both the old and young participants.

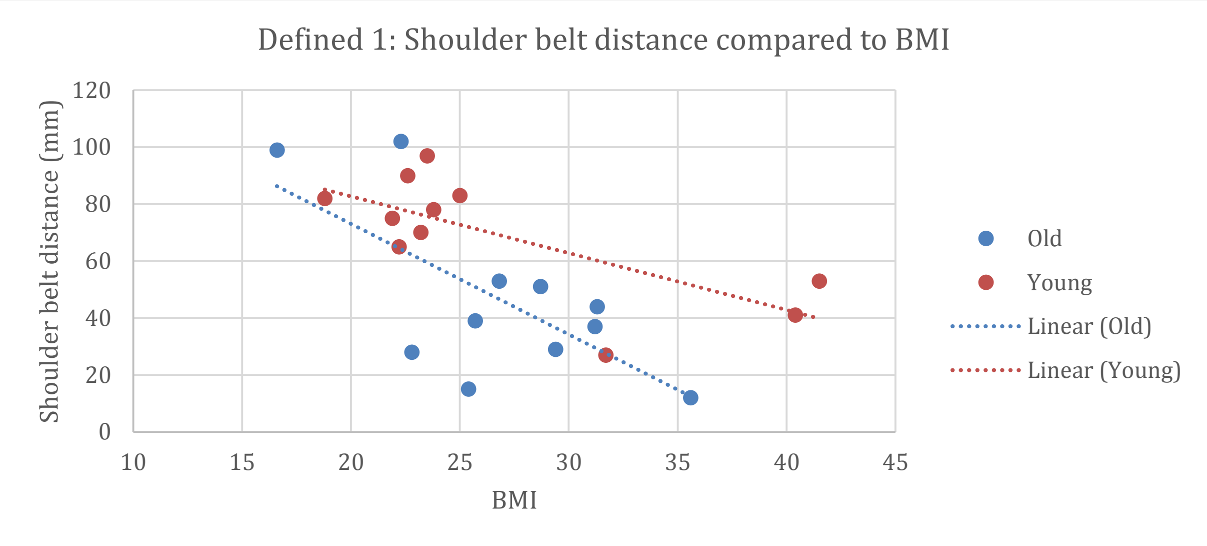


Figure 7.19 - Comparing shoulder belt distance to BMI between young and old in the defined position.

Shoulder belt distance compared to craniovertebral angle

The craniovertebral angle (CVA) was compared to the distance from the suprasternal notch to the upper edge of the shoulder belt (Figure 7.20). This was done in the defined seat position 1 for both the young and old participants. The shoulder belt distance to suprasternal notch was found to increase with increasing CVA among the old participants. Among the young participants this was not found. Since a lesser CVA indicates a more forward head posture which is associated with thoracic kyphosis, the findings indicate that a more kyphotic posture reduces the distance from the suprasternal notch to the upper edge of the shoulder belt among the old participants. This finding is similar to the results of the analysis of the 55 elderly participants from the user study at the exhibition. Thus, the change in posture among elderly seems to affect the shoulder belt distance to the suprasternal notch.

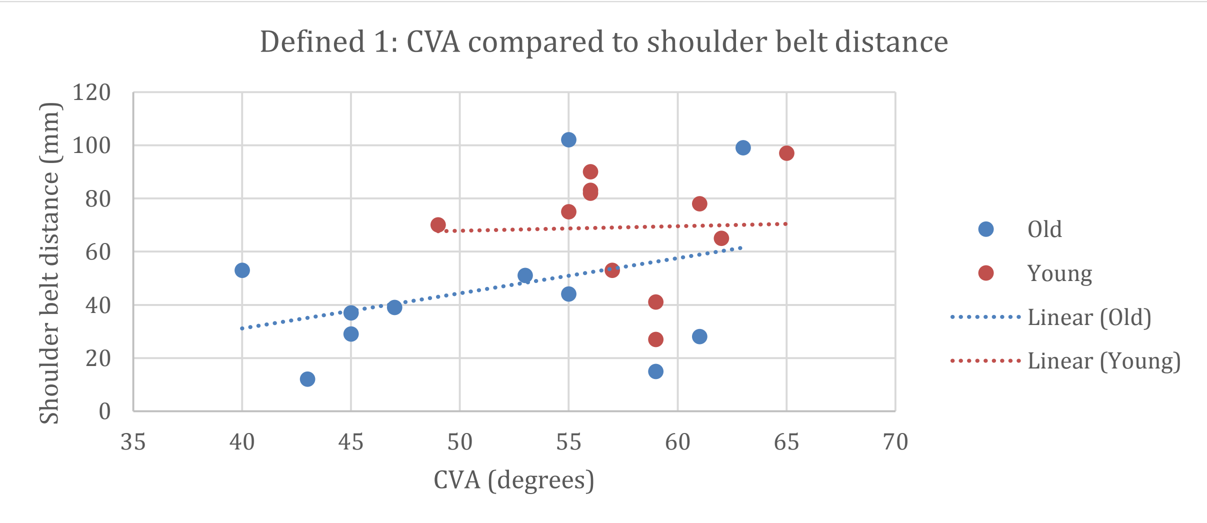


Figure 7.20 - Comparing shoulder belt distance to CVA between young and old in the defined position.

7.2.3 Summary of result: Shoulder belt fit comparison

Shoulder belt position on abdomen

- The findings show that both for the old and young participants, a shoulder belt positioned high in relation to the abdomen was demonstrated among participants within the overweight and obese BMI category.
- The findings show similar trends regarding waist and hip circumference, where participants with greater waist and hip circumference most often demonstrate a shoulder belt positioned high in relation to the abdomen. This trend was also similar for both the old and young participants. This suggest that shoulder belt position in relation to abdomen is affected by BMI, waist and hip circumference and not necessarily related to the age-difference between the groups.

Shoulder belt angle and distance

- The findings show the same trends for both the young and old when comparing the shoulder belt angle and distance to BMI, waist and hip circumference. However, when comparing CVA to the shoulder belt angle and distance a difference was found between the old and young participants. The findings indicate that increased CVA increases the shoulder belt distance and decreases the shoulder belt angle among the old participants. The CVA was not found influencing the shoulder belt angle and distance among the young participants.
- The findings show that the shoulder belt angle was found to increase with increased stature for both young and old.
- No noticeable trend was found in stature influencing shoulder belt distance.

7.3 Lap belt fit comparison between old and young

The lap belt fit was, as in chapter 6, judged based on contact with upper thigh and position on the abdomen and, in the chosen seat position, judged based on the location of the participants anterior-superior iliac spines (ASIS) points in relation to the upper edge of the lap belt.

7.3.1 Lap belt contact with upper thigh and position on abdomen

Regarding contact with upper thigh and position on the abdomen, 10 (91%) of the old participants had the lap belt in contact with the upper thigh and lower on the abdomen, and 1 (9%) did not have the lap belt in contact with the upper thigh and higher on the abdomen (Figure 7.21). This was found the same for both the defined and chosen seat position. Among the young participants, an identical result was also found for both the defined and chosen seat position.

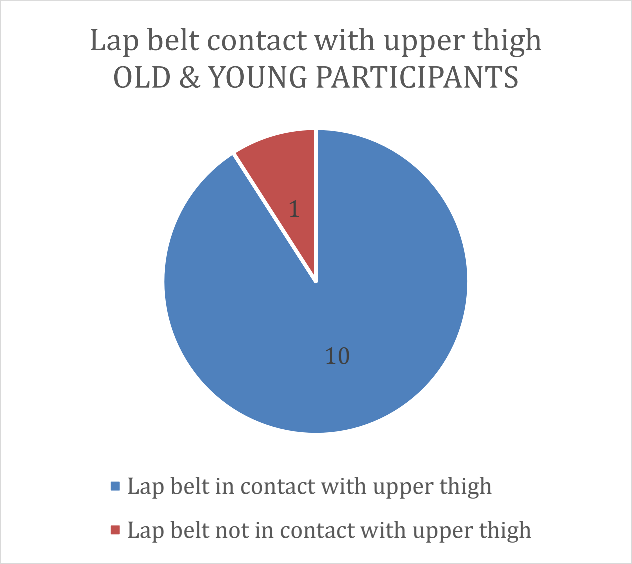
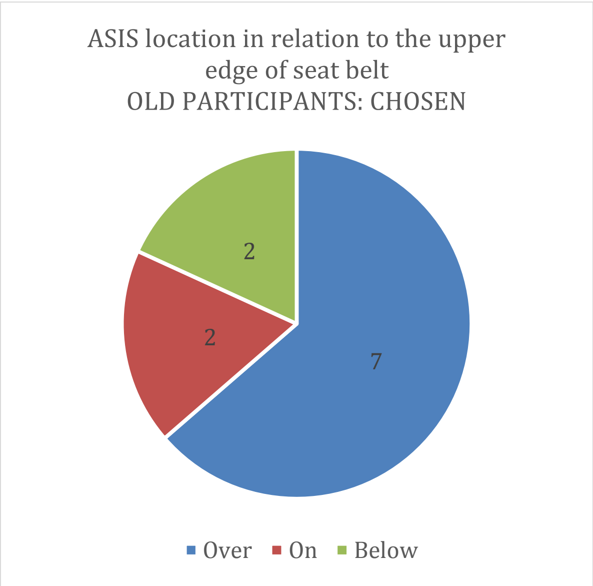


Figure 7.21 - Number of participants judged to have the lap belt in contact with upper thigh and lower on the abdomen (Same result for young and old).

7.3.2 ASIS in relation to upper edge of lap belt

Regarding the location of the participants anterior-superior iliac spines (ASIS) points in relation to the upper edge of the lap belt, in the chosen seat position, 7 (64%) of the old participants had it located over the upper edge of the lap belt, 2 (18%) had it located below the upper edge of the lap belt and 2 (18%) had it located on the upper edge of the lap belt (figure 7.22). Among the young participants, 6 (55%) of the participants had ASIS located below the upper edge of the lap belt, 4 (36%) had it located on the upper edge of the lap belt and 1 (9%) had it located over the upper edge of the seat belt (figure 7.23). These findings indicate that the young participants more commonly had ASIS located below or on the upper edge of the lap belt, than the old participants. When comparing the old participants from the user study in the comparative study to the elderly participants from the user study at the exhibition, a similar result can be seen regarding ASIS location.



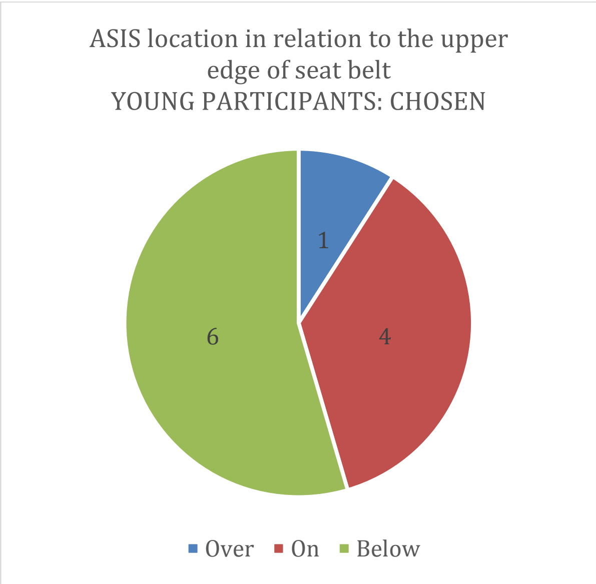


Figure 7.22 and 7.23 -Circle diagram showing the number of old and young participants who had the ASIS point located over, on and below the upper edge of the lap belt in the chosen position.

7.3.3 Lap belt angle

The lap belt angle was measured, using the tool ImageJ, as described in "3.4.2 Defining belt fit parameters". This was done for both the defined seat position 1 and chosen seat position among the 11 old and 11 young participants. The average lap belt angle among the old participants in the defined seat position 1 was 30 degrees and in the chosen seat position the average lap belt angle was 33 degrees. The average lap belt angle among the young participants was 25 degrees in both the defined 1 and chosen seat position. Figure 7.24 describe the distribution of the lap belt angle among the old and young participants in the defined seat position 1. Figure 7.25 describe the distribution of the lap belt angle among the old and young participants in chosen seat position. The result displays a trend of the old participants having a greater lap belt angle than the young participants. When comparing the lap belt angle of the young participants to the elderly participants from the user study at the exhibition, a similar trend of the elderly having greater lap belt angle can be seen.

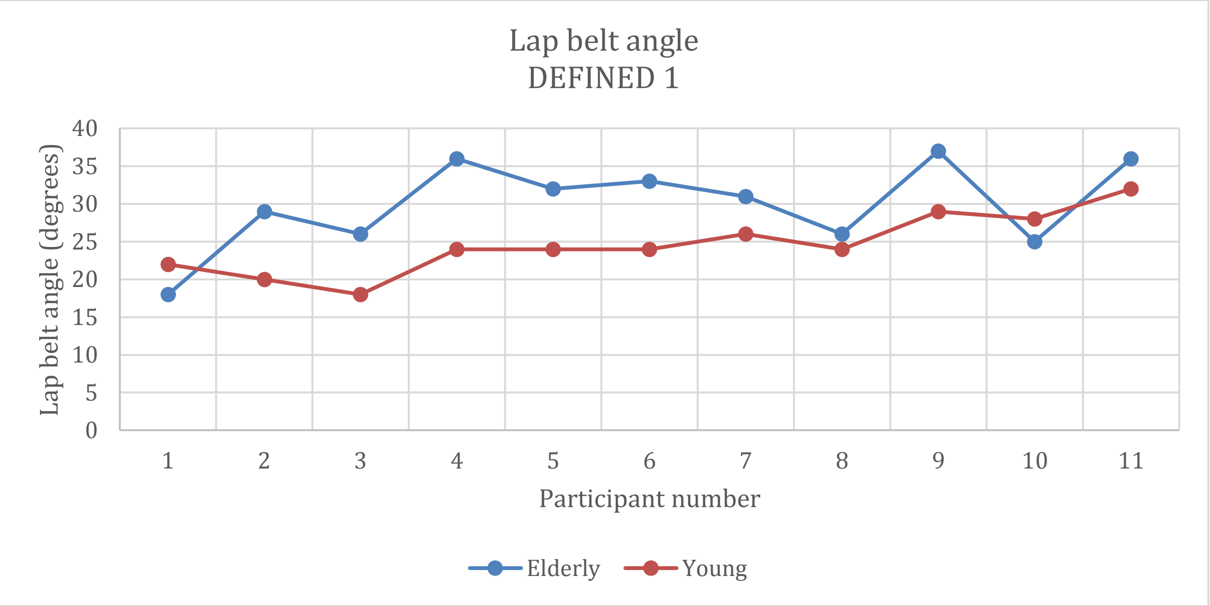


Figure 7.24 - Comparison on lap belt angle between young and old in the defined position.

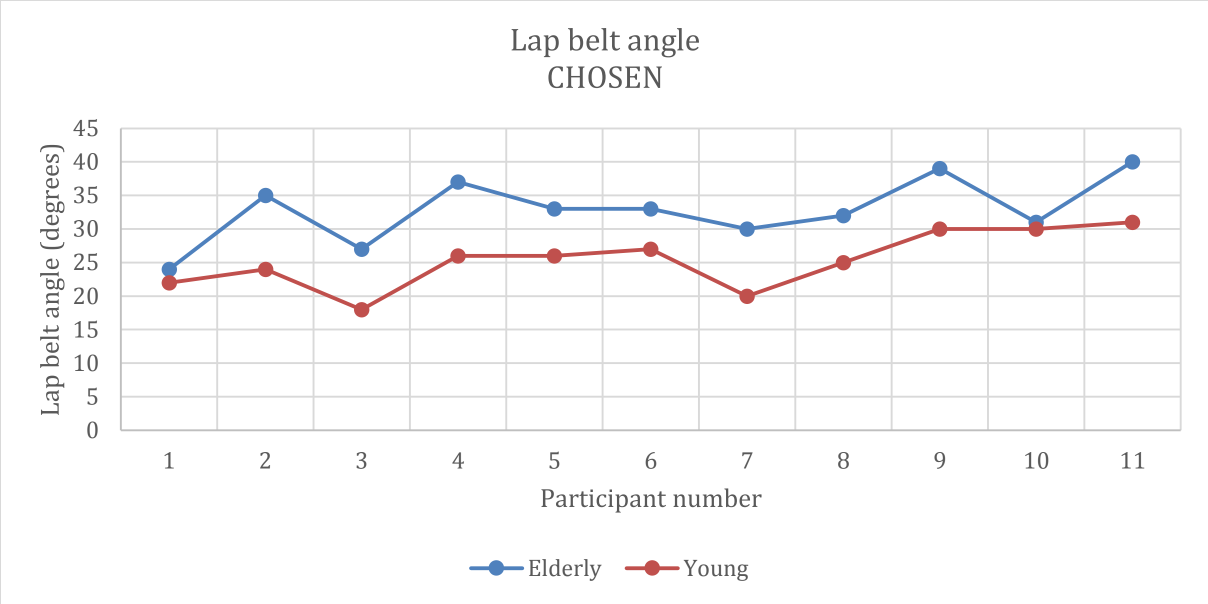


Figure 7.25 - Comparison on lap belt angle between young and old in the chosen position.

7.3.4 Summary of results lap belt fit comparison

Lap belt contact to upper thigh

- No differences were found between the old and young participants in neither the defined or chosen seat position (9% not in contact and 91% in contact).

ASIS in relation to upper edge of lap belt

- The results show that the young participants more commonly demonstrate an ASIS positioned below or on the upper edge of the lap belt than the old.

Lap belt angle

- The lap belt angle was found greater among the old participants in both the defined and chosen seat position.

7.4 Factors influencing lap belt fit comparison in defined seat position

In “7.3 Lap belt fit comparison”, it was found that the largest difference between the young and old participants was the lap belt angle. This factor was therefore further analyzed in the defined seat position to investigate the reason for the difference.

7.4.1 Lap belt angle

The lap belt angle was compared to BMI, waist and hip circumference. The results show a trend that increased BMI leads to increased lap belt angle for both the young and old participants. However, old participants with lower or similar BMI’s as the young participants demonstrated greater lap belt angles than the young participants (figure 7.26). Similar trends were found for waist and hip circumference in comparison with the lap belt angle for both the old and young participants (appendix 9).

The findings indicate that BMI, waist and hip circumference influence the lap belt angle for both the young and old participants. However, there seems to be some other factors, such as body fat distribution or sitting posture, that leads to increased lap belt angle among the old participants.

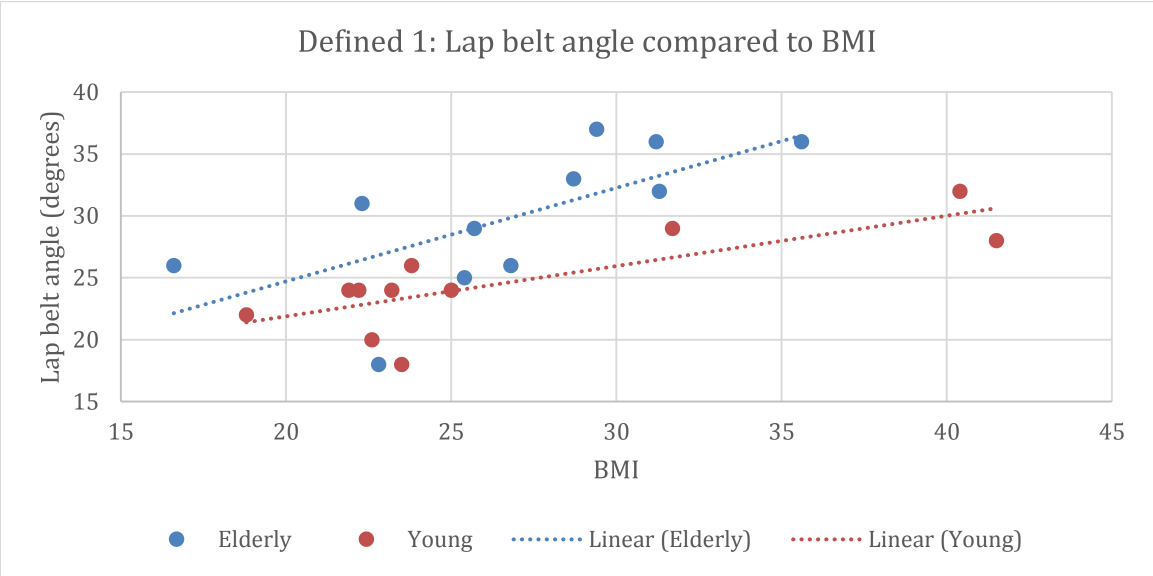


Figure 7.26 - Comparing lap belt angle and BMI between young and old in the defined position.

7.5 Overall belt fit and participant awareness comparison

To find out how many of the participants that overall had good belt fit, the participants were scored good or bad on both shoulder and lap belt fit according to Fong et al. (2016). This was done for the participants chosen seat position.

7.5.1 Overall belt fit

In the chosen seat position, 6 (55%) of the old participants demonstrated good overall seat belt fit and 5 (45%) demonstrated bad overall seat belt fit (figure 7.27). Among the young participants, in the chosen seat position, 9 (82 %) of the participants demonstrated good overall belt fit and 2 (18%) demonstrated bad overall seat belt fit (figure 7.28).

The findings display that good overall belt fit was demonstrated more commonly among the young participants than among the old. This is also the case when comparing the percentage of good overall belt fit among elderly participants from the exhibition to the young participants in the comparative study.

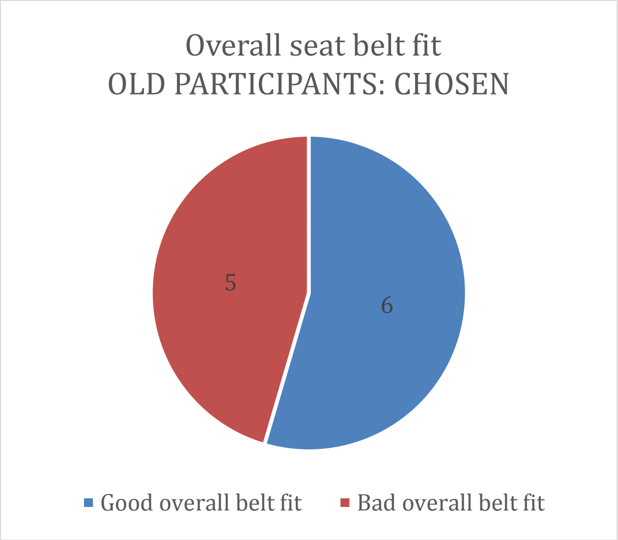


Figure 7.27 - Number of old participants who were judged to have good overall belt fit in the chosen position.

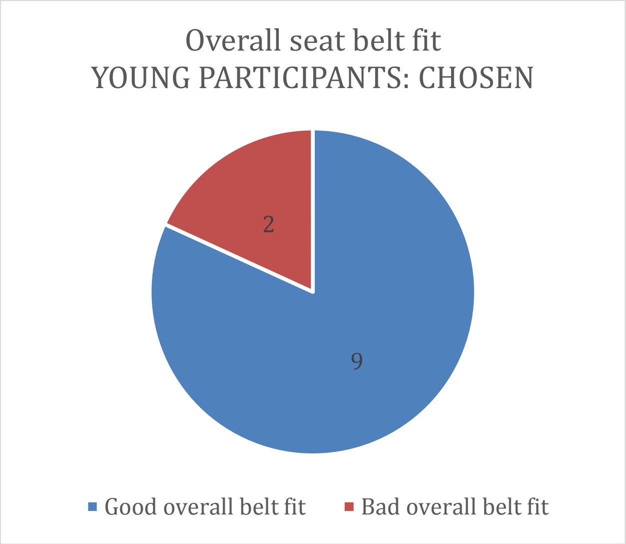


Figure 7.28 - Number of young participants who were judged to have good overall belt fit in the chosen position.

7.5.2 Participant assessment of overall belt fit

During the user studies, the participants were asked to assess their own seat belt fit out of a safety perspective, in the chosen seat position. Out of the 5 (45%) old participants that demonstrated bad overall seat belt fit in the chosen seat position, 4 (80%) assessed their seat belt fit was good/safe and 1 (20%) assessed their seat belt fit as not safe/bad (figure 7.29). Out of the 2 (18%) young participants that demonstrated bad overall seat belt fit in the chosen seat position, 2 (100%) assessed their seat belt fit as not safe/bad (figure 7.30). This result indicate that the old participants are less aware of what good seat belt fit is defined as.

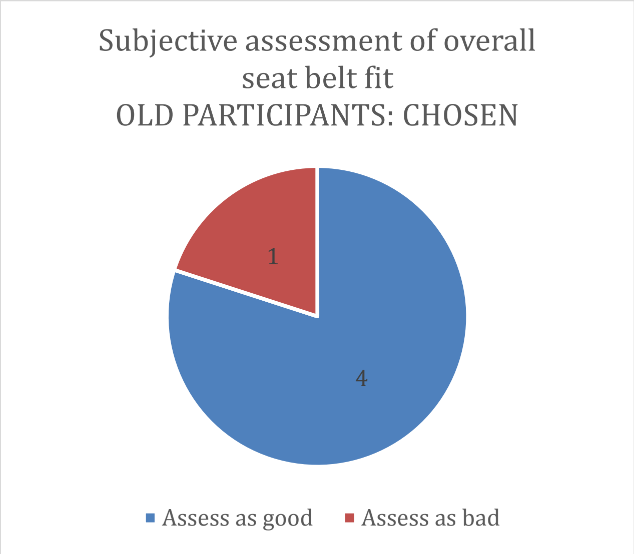


Figure 7.29 - Number of old participants judged as bad overall belt fit who judged their own belt fit as good.

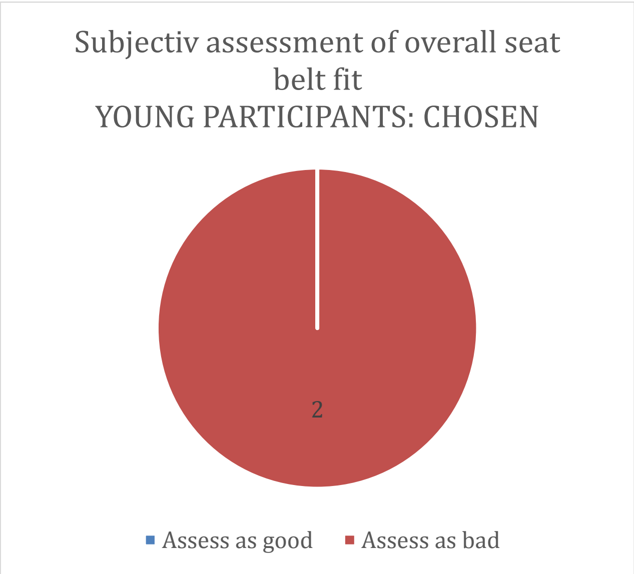


Figure 7.30 - Number of young participants judged as bad overall belt fit who judged their own belt fit as good.

7.5.3 Twisted belt comparison

Among the 11 old participants, 3 (27%) demonstrated a twisted seat belt. Out of these, 1 (9%) demonstrated a twisted shoulder belt and 2 (18%) a twisted lap belt. Among the 11 young participants, 0 % demonstrated a twisted shoulder or lap belt. This result indicate that the elderly is, once again, are less aware of their seat belt fit.

7.5.4 Seat belt slack

When comparing the measured slack between young and old participants the results shows that the young in 10 cases out of 11 have greater slack than the old (Figure 7.31). However, during the user studies the participants were asked to tighten the seat belt themselves and a difference was observed between the two groups. The young participants were subjectively observed to tighten the seatbelt with a higher force than the old, which probably resulted in more induced slack.

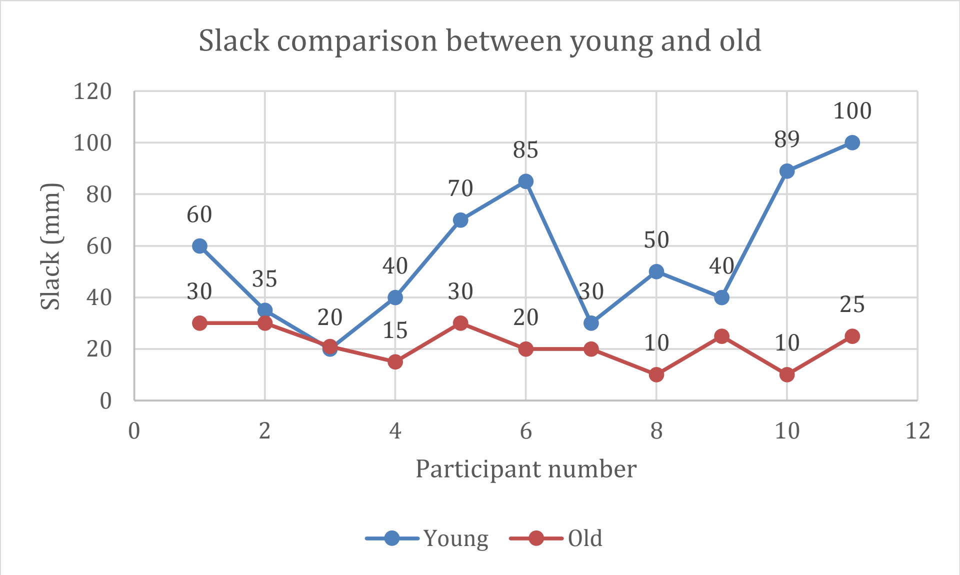


Figure 7.31 - Comparing the measured seat belt slack between young and old participants.

8. Design Guidelines

In this chapter 10 design guidelines are presented as aspects to consider when designing a safe and comfortable passenger environment for elderly. The guidelines are based on the findings from the user studies and backed up by relevant theory.

1. The occupant restraint system should be designed with consideration to changes in body fat distribution among elderly.

The change in body fat distribution among elderly likely influence the positioning of the occupant restraint system, especially the lap belt. In this study the old participants were found to have greater lap belt angle compared to the young participants, regardless of BMI, waist and hip circumference. If fat distribution for elderly men and women is considered, the occupant restraint system would likely better fit old occupants.

2. The occupant restraint system should be designed with considerations to higher BMI and FM among elderly.

Older age groups compared to young have been found to have higher BMI and FM (fat mass). Body mass index has previously been found to be the most important factor influencing the occupant restraint system, regardless of seat position and stature. Occupants with a higher BMI often position the occupant restraint higher on the abdomen and more forward relative the pelvis than those with lower BMI. If considering the higher BMI and FM among elderly men and women, the occupant restraint system would likely better fit old occupants.

3. The occupant restraint system should be designed with consideration to changes in posture among elderly.

Elderly was found to have a more forward head posture which is associated with thoracic kyphosis. This was found to influence the shoulder belt position on the occupant. For instance, a more forward head posture resulted in a shorter distance between the suprasternal notch and the upper edge of the shoulder belt. Therefore, the change in posture should be considered both in a safety as well as comfort perspective.

4. The occupant restraint system should be designed with consideration to the reduced impact tolerance among elderly.

Elderly people have reduced strength and fracture tolerance. Older car occupants are more likely to sustain a life-threatening chest injury. The occupant restraint system should therefore be designed in such way so that the contact area between the occupant and the restrained belt during a crash is as big as possible. This in order to distribute the force over a larger area on the bony structures. This is more important to consider for elderly since they have a weaker skeleton compared to younger.

5. The occupant restraint system should provide feedback about whether or not the occupant uses it correctly.

Elderly was found to have lower awareness of how an occupant restraint system works and should be used compared to younger. In this study, elderly was found to be less aware of their seat belt fit compared to younger since they more commonly thought that they demonstrated good belt fit, when they actually did not. Furthermore, elderly more commonly demonstrated a twisted seat belt compared to younger. The occupant restraint system should therefore provide feedback to the occupant about whether or not the occupant uses it correctly.

6. The occupant restraint system should be designed in congruence with the design of the seat adjustments.

Based on preference and needs, people chose different sitting and seat positions. This influence the occupant restraint system. In this study, the shoulder belt contact from chest to shoulder was affected when the participants adjusted the seat. For instance, some of the participants lost shoulder belt contact from the chest to shoulder after they adjusted the seat. Thus, all parts of the occupant restraint system should be designed in congruence with the seat adjustments to accommodate all preferences and needs.

7. The occupant restraint system and seat adjustments should be designed to be easily reached in a seated position.

Shoulder range of motion has previously been found to decrease linearly from the sixth to ninth decade, statistically significant for abduction and external rotation. In this study, it was found that the participants had problems with reaching the shoulder belt height adjuster. This was observed when the adjustments were described to the participants after each user study was performed. Thus, adjustments regarding the restraint system should be easily reached and operated in a seated position for elderly with a reduced range of motion.

8. The occupant restraint system and seat adjustments should be easy to understand and interact with.

Elderly passengers were observed to be less explorative than the young when it comes to seat and occupant restraint system adjustments. Younger were more likely to learn adjustments by trial and error, compared to older, who rather skipped using the adjustments than trying to figure out how they work. Thus, the adjustments should be easy to understand and interact with, when designing for accommodating elderly.

9. The seat cushion should be designed with less stiffness and less contour when designing for elderly.

Highly contoured seats cannot accommodate differences between people or easily allow change of position. Seats should be designed with gentle contours and firm cushions. However, in this study elderly was found to perceive discomfort related to the seat cushion due to stiffness and the contours between the different parts of it. Thus, the seat should be designed with less contours and less stiff if possible.

10. The occupant restraint system should be designed with consideration to the increased pressure sensitivity among elderly.

Elderly has previously been found to have increased pressure sensitivity. In this study, 5% of the old participants at the exhibition commented on previous discomfort caused by seat belt pressure over the chest and shoulder. This may be caused by elderly's increased pressure sensitivity. Thus, the occupant restraint system should be designed with consideration to the increased pressure sensitivity among elderly.

9. Discussion

This chapter includes a discussion about the results, why the results are of importance, what the explanations of the result are, how the methods influenced the results, limitations of the results and how the results relate to other studies. Furthermore, the guidelines, methods and implementation are discussed.

9.1 Seat belt fit and comfort

According to the findings of the study the old group differed from the young reference group in two aspects related to the seat belt fit. The shoulder belt angle was found greater and the shoulder belt distance to suprasternal notch was found lower among old participants compared to young, regardless of BMI, stature, waist and hip circumference. These findings were found associated with the decreased CVA among the elderly participants and/or the elderlies sitting posture. The decreased CVA among the participants is associated with a more kyphotic posture. If comparing the results from the comparative user study to the user study at the exhibition, the same trend was found regarding shoulder belt distance to the suprasternal notch compared to CVA. However, the CVA was not found to influence the shoulder belt angle in the defined seat position 1, at the exhibition. Thus, the CVA's effect on shoulder belt angle needs more investigation. Regarding the lap belt, the lap belt angle was found greater among the old participants compared to the young. This finding might be associated to the elderlies sitting posture or to a different fat distribution. Elderly was found to demonstrate worse overall belt fit than the young participants. This was the case since elderly more commonly demonstrated a shoulder belt positioned in contact or close to the neck or across the tip of the shoulder, and/or because it was more common among elderly to not demonstrate lap belt contact to upper thigh.

Another factor related to the seat belt fit, found among both young and old participants, was that the shoulder belt wasn't in contact with the participants bodies from the chest to the shoulder. It was found more common among women to not demonstrate contact. This finding is likely associated with a greater chest circumference among women and thus it is recommended to further investigate this.

The analysis of the seat belt fit was done through subjective assessments and objective measurements. The subjective assessments of how the shoulder and lap belt was positioned could have affected the result. To validate the assessments, some cases were shown to a safety expert which assessed similar results. This validation was not done for all cases. However, all assessments were done separately between the two thesis writers to further validate the result. Regarding measuring angles and distances in the photographs, it was sometimes the case that participant clothing covered certain areas such as the suprasternal notch. During the user studies the participants were asked to remove clothing such as jackets and scarfs. However, at the exhibition some participants did not want to remove these. This resulted in that when measuring the photographs of these, it was harder to estimate which might have affected the results.

The results are of importance since the positioning of the shoulder and lap belt is affected, which might lead to comfort and safety issues. For instance, a short shoulder belt distance to suprasternal notch may lead to comfort problems with a shoulder belt in contact or close to the neck. An increased shoulder belt angle may also increase the risk of a shoulder belt positioned further out on the shoulder which can become a safety issue since it may slip off the shoulder during a crash. Furthermore, an increased lap belt angle is an indicator of more webbing pulled out from the reactor which may lead to that the belt needs to travel a longer distance before it restraints the pelvic bone.

There are some limitations with the result. Since a decreased CVA is associated with, and not the same as a kyphotic posture, it cannot be stated with certainty that a more kyphotic posture is the reason for the findings. Furthermore, since the sitting posture of the participants was not analyzed, further studies are necessary to investigate the elderlies sitting postures effect on the shoulder and lap belt positioning. To investigate if elderlies body fat distribution affects the lap belt angle, further studies are required. In this project, the waist and hip circumference were measured while the participants were standing. To further investigate the influence of elderlies' fat distribution, it would be beneficial to measure the waist and hip circumference of the participants while they are seated and to measure shoulder, chest and thigh circumference. This since these measurements likely influence the seat belt fit.

If comparing the results to the study by Fong et al. (2016), some similarities were found. They used a front view photograph for the assessment of belt fit whereas this project used both a side view and front view photograph. However, the percentage of participants demonstrating overall good belt fit were according to Fong et al. (2016), 35%, and according to this project's results 58%, in the user study at the exhibition. The reason behind this might be because all participants had their own car and thereby different conditions in their study. This project used the same car model and conditions for all participants which might explain the difference in result. According to Fong et al. (2016), their findings for the lap belt fit likely reflected differences in age-related fat distribution among women and men. Furthermore, Fong et al. (2016), found poor lap and shoulder belt fit relatively common among elderly regardless of BMI. These findings are congruent with this project's findings on lap belt angle which suggests that further investigating on how body fat distribution among elderly influence the seat belt fit is of importance.

9.2 Experience of discomfort

According to the findings, discomfort among elderly was associated with the headrest, lumbar support and seat cushion. However, in a static test environment, no noticeable difference was found regarding how the older group experience discomfort in test car compared to the young reference group. The young participants reported more discomfort than the elderly participants. This can be interpreted in two different ways. Either it shows indications that older sit more comfortable in the test car compared to the young reference group, or it shows indications about a difference in attitude probably based on previous experienced among the older participants. In our belief, the latter is most probably the cause. The result could have been different if the test was done dynamic and over a longer period of time, which needs to be investigated to make any further conclusions.

We think that the difference in attitude between the old and young group is of importance. The participants in the older group seemed to be more forgiving and had a different mindset towards the seat belt and adjusting the seat and the seat belt. The older participants had more of an attitude like "I'm fine as it is, I have been in worse situations" and did not explore the adjustments or complain much about discomfort. It seemed like they rather skipped using an adjustment than ask for help if they could not find it or did not understand how to use it. One example in the test car would be adjusting the lumbar support. In some cases, the old participants commented on the lack of lumbar support, when asked about discomfort, even though it could have been adjusted if they knew how to adjust it. In comparison, when the young were asked to adjust the seat as they preferred they were more explorative. They figured out how the adjustments worked by "trial and error" and asked for more help compared to the older participants. They had more of an attitude like "Let's explore the adjustments and see how comfortable I can sit". Thus, young learn how to sit comfortably but the older did not explore to the same extend and did not seem to bother as much, even though they did experience discomfort. We think elderly might have been influenced by their previous experiences of older car models since they often referred to previous experiences such as:" Compared to what I have experience before this is very good". This might explain why none of the elderly reported more than one discomfort, but the young did. This might be affected by the differences in experiences of older car models from the past with less comfort.

Coxon et al. 2014, found add-on accessories, such as seat cushions, commonly used among elderly to improve comfort based on an Australian population. In this study, use of add-on accessories to improve comfort was not found common and only a few mentioned it. The differences in result may be associated with the cars the test participants own. In other words, the use of accessories may be more common among elderly who own older cars with worse comfort than modern cars.

Regarding the discomfort the participants experienced in the test car, there are several important aspects to consider which may have had an impact of the result. This would be the environment at the exhibition, the static none driving condition and the time they sat in the car. The stressful environment and the level of impressions surrounding an exhibition area may have influenced the participants subjective evaluation of discomfort. However, during the interview the car door was closed which lead to a calmer environment. The test was also done static and if the test would have been dynamic it could have influenced how they chose to sit and how they would perceive the discomfort in the car. However, the participants were always asked to enter the car as if they were about to travel in a real-life situation. Finally, the time is an important factor when it comes to discomfort and more people may have perceived discomfort if the study would have been persecuted over a longer period of time. These factors may explain why there were only a few participants reporting discomfort in the test car and only 3 out 55 who reported more than one discomfort at the exhibition.

The old participants at the exhibition and in the comparative user study consisted of people who travel by car often and mostly as drivers compared to the young reference group who were more often passengers and did not travel in cars as often. One could argue that elderly people who visit exhibitions might represent the active type of seniors. The old participants who applied interest in participating in the comparative study, according to themselves, were people who had a special interest in cars. However, the young reference group was picked randomly and were not necessarily interested in cars which may have influenced the result and the comparison. The travel frequency among the older participants may have had an impact on how the participants perceived the comfort in the test car and how well they could recall previous experience discomfort in cars they often travel in. In that case the result may have been different if the study would have included a bigger variety of elderly people to better represent the average car traveler. The active seniors may have adjusted their own seat over time and may not reflect as much about the discomfort in their own cars as the less active seniors would have when they travel.

9.3 Preferred sitting position, awareness, and attitude

Based on the findings, the older participants prefer to sit higher than younger. The reason was most often because they want to follow the traffic and “be a part of driving” which was important for them to feel safe. This was not mentioned among the younger reference group and might be worth considering in future studies. Regarding preferred backrest angle no differences were found between the young and old. Both seemed to prefer a more upright backrest angle. A difference was found regarding the horizontal placement of the seat. The young participants seem to more commonly prefer to adjust the seat forward than the old.

Once again, there were a difference between young and old related to attitude and awareness. Elderly was found to have relatively low awareness of how an occupant restraint system works and should be used compared to young. This was because a large portion within the elderly group thought that they demonstrated safe/good belt fit when they actually did not. The old seemed to be more considered about what happens outside the car, whereas the young seemed more concerned about safety inside the car. The young also seemed to have a better understanding of how the seat belt should be used and was more observant how they placed it on their bodies compared to the old group. In the older group they did not really reflect much about the seat belt and they were not as observant how they placed it on their bodies. The low awareness was also contributed to that the elderly more commonly demonstrated a twisted seat belt than the younger. One of the older participants in the comparative user study had the lap belt twisted two times and noticed it first when we asked about it. When participants afterwards were told how and why they should use the seat belt in a certain way some commented “I remember the time when cars did not even have seat belts”. They had an attitude like “as long as I wear the seat belt, it’s all good” compared to young who seems more aware of the importance of placing it good.

9.4 Guidelines

The guidelines have not been tested or evaluated. Thus, to use the guidelines in practice, further development and evaluation is needed. However, according to the findings the guidelines cover the most important topics that needs to be considered early in the design process to accommodate the needs of elderly and to avoid problems that already exist with both the seat belt and the passenger environment as a whole. The guidelines focus on including elderly as passengers but are also applicable for including a heterogenous population. If the topics covered in the guidelines are discussed and enlightened early in the development process it will create a better condition to design a safe and comfortable passenger experience for a heterogenous population.

9.5 Methods and implementation

Defined seat positions

Regarding the two defined seat positions, used during the exhibition, the idea was to investigate how the shoulder belt height level affected the shoulder belt fit. The results did not display any large differences between the two groups. Furthermore, because of the lower number of participants in the defined seat position 2 and because of that three participants accidently had the shoulder belt adjusted to the wrong level, the comparison was affected. Thus, it might have been better to only use one defined seat position for all participants in this study. However, if future studies want to investigate the effect of the shoulder belt height adjustment, it is suggested that a comparison is made between the lowest and the highest level. This may display larger differences than the ones found in this project, where the lowest and second lowest shoulder belt height level were used.

The three cases that accidentally had the shoulder belt adjusted to the wrong level could have been avoided if a checkbox would have been included in the interview document. It is therefore also recommended that future studies include this. None at the exhibition nor the comparative study used the shoulder belt height adjustment in their chosen position. After the interview the adjustment were introduced to all participants and only a handful knew about the adjustment even though they did not use it.

Measurements

Regarding measuring the ASIS location in relation to the upper edge of the lap belt, the method used in this project did not work as good as expected. When analyzing the photographs, it became apparent that some participants must have been incorrectly measured or that these participants did not point out their ASIS points correct. Thus, using the method developed in this project could only be used to quantify if the participants had the ASIS located over, on or below the upper edge of the lap belt. In similar projects, in the future, it is therefore recommended to develop and use another method if the goal is to measure the distance. However, using a skeleton model to show where the ASIS points are located for the participants worked very well.

Regarding the method developed for measuring the seat belt slack, there were a few concerns that needs to be considered in future studies. The first concern was that the participants themselves were allowed to tighten the seat belt. According to the results and observations made during the user studies, this affected the outcome since they tightened the seat belt differently. The other concern, which was noticed in a few cases, was that the stickers used in the method did not stick good enough on the seat belt. Thus, in future studies it is recommended that the test leader should tighten the seat belt and to use stickers that properly stick to the seat belt.

10. Conclusions

This chapter answers the aim and research questions of the project. Conclusion are drawn based on the findings of the project.

10.1 How does aging affect seat belt fit and comfort for passengers in cars?

Seat belt fit

According to the findings of the study the old group differed from the young reference group in two aspects related to the seat belt fit. The shoulder belt angle was found greater and the shoulder belt distance to suprasternal notch was found lower among old participants compared to young, regardless of BMI, stature, waist and hip circumference. These findings were found associated with the decreased CVA among the elderly participants and/or the elderlies sitting posture. The decreased CVA among the participants is associated with a more kyphotic posture. If comparing the results from the comparative user study to the user study at the exhibition, the same trend was found regarding shoulder belt distance to the suprasternal notch compared to CVA. However, the CVA was not found to influence the shoulder belt angle in the defined seat position 1, at the exhibition. Thus, the CVA's effect on shoulder belt angle needs more investigation. Regarding the lap belt, the lap belt angle was found greater among old participants compared to the young. This finding might be associated to the elderlies sitting posture or to a different fat distribution. Elderly was found to demonstrate worse overall belt fit than the young participants. This was the case since elderly more commonly demonstrated a shoulder belt positioned in contact or close to the neck or across the tip of the shoulder, and/or because it was more common among elderly to not demonstrate lap belt contact to upper thigh.

Comfort

According to the findings from the project there are age-related factors influencing the comfort of elderly passengers. Since the shoulder belt distance was found smaller among old participants, the shoulder belt might lead to discomfort if travelling during longer periods of time. Based on the results, elderly more commonly also seem to prefer a less stiff and contoured seat compared to young. Furthermore, elderly is more sensitive to pressure pain which may be the reason for why they prefer less set cushion stiffness and contour.

10.2 How does the intended user group experience comfort in today's cars compared to a young reference group?

According to the findings, discomfort among elderly was associated with the headrest, lumbar support and seat cushion. However, in a static test environment, no major difference was found regarding how elderly experience comfort in today's cars compared to young. The young participants reported more discomfort than the elderly participants. However, a difference in attitude were observed which may have balanced up between the two groups. Furthermore, the result suggests that there is a difference in priorities between young and old and how they define comfort. Young seems to be more seat and legroom oriented whereas a good field of sight as passengers are more important among the elderly.

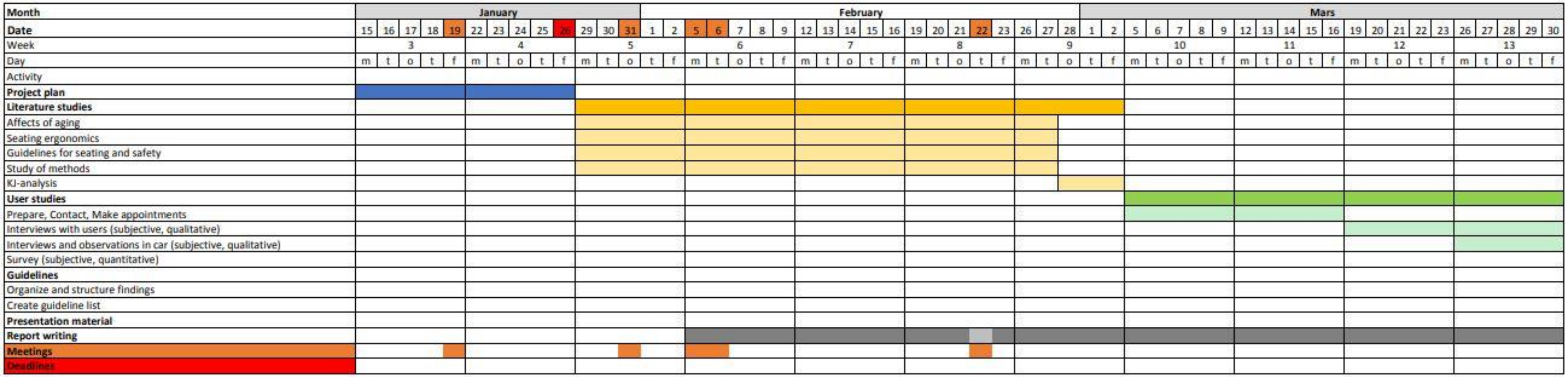
10.3 How does elderly prefer to sit as passengers and how aware are elderly of safety related to seat belt fit compared to a young reference group?

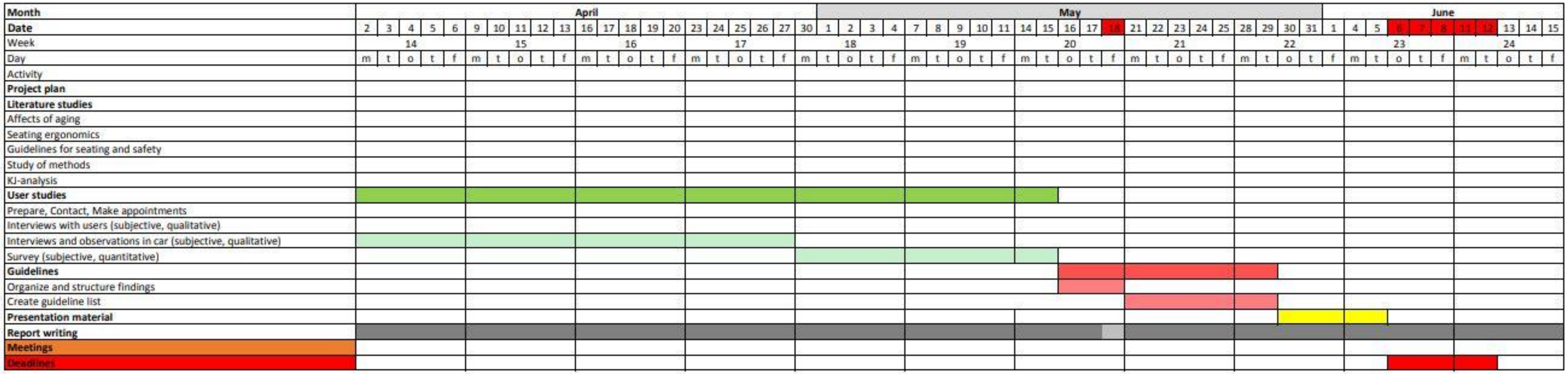
Based on the findings, elderly prefer to sit higher than younger. The reason for this is according to the findings that they want to see the traffic and “be a part of driving”. Regarding preferred backrest angle no differences were found between the young and old. Both groups preferred a more upright backrest angle. A difference was found regarding the horizontal placement of the seat. The young participants seem to more commonly prefer to adjust the seat forward than the old.

According to the findings of the project there is a difference between young and old related to attitude and awareness. Elderly was observed to have a different attitude towards using the adjustments compared to younger. The elderly was found less explorative than the younger. Elderly was also found to have relatively low awareness of how an occupant restraint system works and should be used compared to young. This low awareness was contributed to that a large portion of elderly thought that they demonstrated safe/good seat belt fit when they actually did not. It was also contributed to that the elderly more commonly demonstrated a twisted seat belt than the younger.

Appendix

Appendix 1: GANTT-schedule





Appendix 2: Anonymity agreement for the comparative user study

Studie av sittkomfort och säkerhet för äldre passagerare i bil

Chalmers genomför ett vetenskapligt forskningsprojekt om äldre passagerare i bil för att ytterligare öka komfort och säkerhet i dagens och framtidens bilar. I forskningsprojektet ingår denna studie som också är en del av ett examensarbete på masterprogrammet Industrial Design Engineering.

Som deltagare i studien kan du avbryta när du vill utan att motivera varför. Studien tar cirka 10 minuter och vi kommer att mäta midjemått, höftmått, vikt och längd på alla deltagare samt fotografera dig stående utanför bil och sittande i bil. Alla foton kommer att avidentifieras och du kommer att vara anonym. Avidentifierade bilder kan komma att användas och publiceras i en rapport.

Ansvarig för studien är professor Anna-Lisa Osvalder som också är examinator för examensarbetet. Anna-Lisa arbetar på institutionen för Produkt och produktionsutveckling, Chalmers:
(Tel: 0317723643, Mejl: anna-lisa.osvalder@chalmers.se)

Försöksledare är:
Svante Alfredsson
Robin Ankartoft

Genom att skriva under godkänner du att delta i studien på ovanstående villkor:

Underskrift:____

Namnförtydligande:_______________________________________

Datum:__________________ Ort: ________________________________

Appendix 3: Information sheet handed out during the user study at the exhibition

Studie av sittkomfort och säkerhet för äldre passagerare i bil

Chalmers genomför ett vetenskapligt forskningsprojekt om äldre passagerare i bil för att ytterligare öka sittkomfort och säkerhet i dagens och framtidens bilar. I forskningsprojektet ingår denna studie som också är en del av ett examensarbete på masterprogrammet
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Försöksledare är:
Svante Alfredsson
Robin Ankartoft

Appendix 4: Structured Interview documents comparative study

Information om deltagare

I detta frågeformulär söker vi efter din upplevelse av sittkomforten i dagens passagerarsäten. Målet är att samla in data för att kunna göra förbättringar för framtiden. Vi vill även gärna ha lite information om dig som deltagare. Personlig information kommer ej publiceras eller spridas på något sätt, utan är endast till för att vi ska kunna föra statistik. Foton som tas kommer avidentifieras.

*Obligatorisk

FOTO KYPHOS *

- Check
- Övrigt:__________

Nummer:

____

Kön

- Man
- Kvinna

Ålder:

____

Längd (cm)

____

Vikt (kg)

____

Midjemått (cm)

____

Höftmått (cm)

____

Lokaliserat ASIS? Markera endast en oval.

- Ja
- Övrigt:__________

På vilket sätt färdas du oftast i bil?

- Som förare
- Som passagerare i framsätet
- Som passagerare i baksätet
- Som passergare eller förare
- Övrigt:__________

Hur många gånger i veckan åker du bil?

- 1 dag per vecka
- 2-3 dagar per vecka
- 4-6 dagar per vecka
- Varje dag
- Övrigt:__________

Obehag

Sitt i bestämd position med bälte - ta kort - ta av bälte - Låt dem ställa in stolen - ta på bälte - öppna dörren - ta kort - stäng dörren och börja med frågor. Läs fråga och låt försökspersonen själv visa vart på deras egna kropp dem upplever obehag.

Foto designläge

- Framifrån och från sidan

Be försöksperson ställa in säte för färd (fråga om dem behöver hjälp med någon inställning) *

- Egenvalt läge framifrån och från sidan
- Egenvalt läge med handen upp från sidan

Känner du obehag någonstans på kroppen där du sitter nu? Om du känner obehag på flera ställen, svara där du känner mest! Du kommer få möjlighet att säga fler obehag sen.

- Upplever inget obehag Bröstkorg
- Axlar/Arm
- Nacken Hals Övre rygg
- Nedre rygg Mage
- Övre lår
- Undre lår Rumpa Knä
- Övrigt:__________

På en skala från 1-10 hur mycket obehag upplever du i ....? Där 1 är inget obehag alls och 10 är så mycket obehag att du vill ta av dig bältet och gå ur bilen.

1 2 3 4 5 6 7 8 9 10

Vad i bilen är den främsta anledningen till obehaget tror du? Markera alla som gäller.

- Nackstödet
- Ryggstödet
- Sätesdynan
- Bältet
- Övrigt:__________

Ytterligare obehag

Är det något mer ställe på kroppen du känner obehag som är värt att nämna?

- Upplever inget mer obehag
- Bröstkorg
- Axlar/Arm
- Nacken Hals
- Övre rygg
- Nedre rygg
- Mage
- Övre lår
- Undre lår
- Rumpa
- Knä
- Övrigt:__________

På en skala från 1-10 hur mycket obehag upplever du i ....? Där 1 är inget obehag alls och 10 är så mycket obehag att du vill ta av dig bältet och gå ur bilen

1 2 3 4 5 6 7 8 9 10

Vad i bilen är den främsta anledningen till obehaget tror du? Markera alla som gäller.

- Nackstödet
- Ryggstödet
- Sätesdynan
- Bältet
- Övrigt:__________

Inställning nu

Fortsätt sitta som du gör så skulle vi vilja ta några mått vad gäller sätet.

Avstånd till nackstöd (cm)

____

Vald ryggstödssvinkel (grader) *

____

Valt stolsläge (cm)(Design=5cm från bakersta=12 cm från kant framifrån)(mät från framkant)

____

Bilbältet

Utan att justera bältet, hur upplever du att bältet sitter på dig nu ur ett säkerhetsperspektiv?

- Bra Dåligt Vet ej
- Övrigt:__________

ASIS mått (mm)

____

ASIS placering (negativt = under)

- Ovanför bälteskant
- Under bälteskant
- Övrigt:__________

Slack (mm)

____

Vad ställer du in i vanliga fall?

Vanligtvis när du ställer in sätet. Vilka inställningar använder du då? Till exempel skjuta fram eller bak sätet

- Skjuta fram eller bak stolen
- Höja eller sänka stolshöjden
- Vinkla ryggstödet
- Vinkla sittdynan
- Justera ländryggsstödet
- Justera ryggstödets sidostöd
- Förlänga eller förkorta sittdynans längd
- Justera axelbältets höjd
- Justera nackstödet
- Övrigt:__________

Vad är anledningen till att du gör dessa inställningar?

- Vill sitta mer bekvämt
- Vill sitta tillräckligt högt för att se ut
- Vill kunna sträcka ut benen
- Vill sitta mer avslappnat
- Vill känna mig säker
- Vill inte uppleva någon obekvämlighet
- Vill att bältet ska sitta bekvämt
- Övrigt:__________

Accessoarer

Vi har sett att användade av accessoarer som exempelvis kuddar är relativt vanligt. Vi är intresserade av att ta reda på vad anledningen till detta är. Använder eller har du använt några accessoarer i din bil? med accessoarer menar vi tilläggsprodukter så som kuddar, filtar eller olika typer av stöd etc som du använder för att förbättra komforten eller minska obehag.

- Använder inga accessoarer
- Sittdyna eller liknande
- Ländryggstöd eller liknande
- Nackkudde eller liknande
- Knästöd eller liknande
- Bältesdyna eller liknande
- Övrigt:

Vad är främsta anledningen till detta?

- För att få bättre sikt
- Underlaget är för hårt
- Extra stöd
- Skav
- Övrigt:__________

Appendix 5: Structured Interview document Exhibition

Information om deltagare

I detta frågeformulär söker vi efter din upplevelse av sittkomforten i dagens passagerarsäten. Målet är att samla in data för att kunna göra förbättringar för framtiden. Vi vill även gärna ha lite information om dig som deltagare. Personlig information kommer ej publiceras eller spridas på något sätt, utan är endast till för att vi ska kunna föra statistik. Foton som tas kommer avidentifieras.

*Obligatorisk

FOTO KYPHOS *

- Check
- Övrigt:__________

Nummer *

____

Kön

____

Ålder

____

Längd (cm)

____

Vikt (kg)

____

Midjemått (cm)

____

Höftmått (cm)

____

Lokaliserat ASIS? Markera endast en oval.

- Ja
- Övrigt:___________

På vilket sätt färdas du oftast i bil? Markera endast en oval.

- Som förare
- Som passagerare i framsätet
- Som passagerare i baksätet
- Som passergare eller förare
- Övrigt:___________

Hur många gånger i veckan åker du bil?

- 1 dag per vecka
- 2-3 dagar per vecka
- 4-6 dagar per vecka Varje dag
- Övrigt:___________

Obehag

Sitt i bestämd position med bälte - ta kort - ta av bälte - Låt dem ställa in stolen - ta på bälte - öppna dörren - ta kort - stäng dörren och börja med frågor. Läs fråga och låt försökspersonen själv visa vart på deras egna kropp dem upplever obehag.

Foto designläge *

- Framifrån och från sidan

Be försöksperson ställa in säte för färd (fråga om dem behöver hjälp med någon inställning) *

- Egenvalt läge framifrån och från sidan
- Egenvalt läge Nacke från sidan
- Egenvalt läge med handen upp från sidan

Känner du obehag någonstans på kroppen där du sitter nu? Om du känner obehag på flera ställen, svara där du känner mest! Du kommer få möjlighet att säga fler obehag sen.

- Upplever inget obehag
- Bröstkorg
- Axlar/Arm
- Nacken Hals
- Övre rygg
- Nedre rygg
- Mage
- Övre lår
- Undre lår
- Rumpa
- Knä
- Övrigt:_________________

På en skala från 1-10 hur mycket obehag upplever du i ....? Där 1 är inget obehag alls och 10 är så mycket obehag att du vill ta av dig bältet och gå ur bilen.

1 2 3 4 5 6 7 8 9 10

Vad i bilen är den främsta anledningen till obehaget tror du? Markera alla som gäller.

- o Nackstödet
- o Ryggstödet
- o Sätesdynan
- o Bältet
- o Övrigt:__________________

Ytterligare obehag

Är det något mer ställe på kroppen du känner obehag som är värt att nämna? Markera alla som gäller.

- o Upplever inget mer obehag
- o Bröstkorg
- o Axlar/Arm
- o Nacken Hals
- o Övre rygg
- o Nedre rygg
- o Mage
- o Övre lår
- o Undre lår
- o Rumpa
- o Knä
- o Övrigt:____________________

På en skala från 1-10 hur mycket obehag upplever du i ....? Där 1 är inget obehag alls och 10 är så mycket obehag att du vill ta av dig bältet och gå ur bilen

1 2 3 4 5 6 7 8 9 10

Vad i bilen är den främsta anledningen till obehaget tror du? Markera alla som gäller.

- o Nackstödet
- o Ryggstödet
- o Sätesdynan
- o Bältet
- o Övrigt:_____________________

Inställning nu

Avstånd till nackstöd (cm)

____

Vald ryggstödssvinkel (grader) *

____

Valt stolsläge (cm) (Design=5cm från bakersta=12 cm från kant framifrån) (mät från framkant)

____

Bilbältet

Utan att justera bältet, hur upplever du att bältet sitter på dig nu ur ett säkerhetsperspektiv?

- Bra
- Dåligt
- Vet ej
- Övrigt:_________________

ASIS mått (mm)

____

ASIS placering (negativt = under)

- Ovanför bälteskant
- Under bälteskant
- Övrigt:________________

Slack (mm)

____

Accessoarer

Vi har sett att användadade av accessoarer som exempelvis kuddar är relativt vanligt. Vi är intresserade av att ta reda på vad anledningen till detta är.Använder eller har du använt några accessoarer i din bil? med accessoarer menar vi tilläggsprodukter så som kuddar, filtar eller olika typer av stöd etc som du använder för att förbättra komforten eller minska obehag.

- Använder inga accessoarer
- Sittdyna eller liknande
- Ländryggstöd eller liknande
- Nackkudde eller liknande
- Knästöd eller liknande
- Bältesdyna eller liknande
- Övrigt:_______________________

Vad är den främsta anledningen till detta?

- För att få bättre sikt
- Underlaget är för hårt
- Extra stöd
- Skav
- Övrigt:________________

Tidigare upplevt obehag

Har du upplevt något obehag i din eller någon annans bil som du ofta åker i? I så fall vart på kroppen har du känt obehag?

- Inte upplevt obehag
- Bröstkort
- Axlar/arm
- Nacke Hals
- Övre rygg
- Nedre rygg
- Mage
- Övre lår
- Undre lår
- Rumpa
- Knä
- Övrigt:__________________

Vad i bilen är den främsta anledningen till obehaget tror du?

- Nackstödet
- Ryggstödet
- Sätesdynan
- Bältet
- Övrigt:______________________

Har du någon gång upplevt obehag på grund av säkerhetsbältet? I så fall varför?

- Skav i halsen
- Övrigt:______________

Appendix 6: Demographics of participants

Table 1 - Demographics of all participants in the user study at the exhibition.

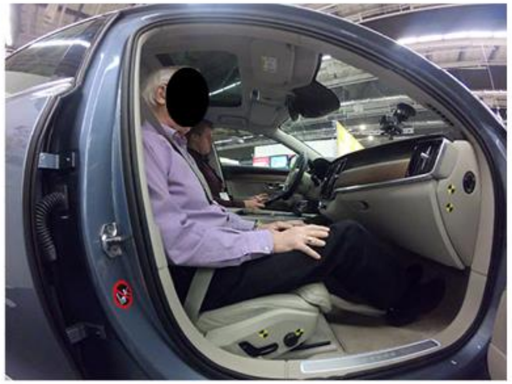
Nr.	Sex	Age (Years)	Stature (cm)	Weight (kg)	Waist circ. (cm)	Hip circ. (cm)	BMI	Nr.	Sex	Age (Years)	Stature (cm)	Weight (kg)	Waist circ. (cm)	Hip circ. (cm)	BMI
1	Female	67	169	89	115	123	31	29	Male	75	183	120	134	129	36
2	Male	67	181	83	103	107	25	30	Female	80	164	74	100	112	28
3	Male	65	186	84	96	105	24	31	Female	77	159	65	87	104	26
4	Male	69	172	73	101	103	25	32	Male	69	187	74	92	105	21
5	Male	71	183	75	101	100	22	33	Female	65	173	63,5	80	101	21
6	Male	79	182	82	104	105	25	34	Male	76	173	73	104	109	24
7	Female	75	163	60	82	99	23	35	Female	72	155	54	89	99	23
8	Female	70	168	75	104	109	27	36	Male	75	186	89	114	112	26
9	Female	71	184	76		111	22	37	Female	76	169	74	94	107	26
10	Male	76	190	90	107	112	25	38	Male	69	185	70	94	102	21
11	Female	79	168	60	87	101	21	39	Male	79	178	72	94	107	23
12	Male	80	176	69	90	101	22	40	Male	70	184	87	116	107	26
13	Female	76	165	72	101	105	26	41	Male	70	175	76	90	98	25
14	Female	70	164	62	96	97	23	42	Male	80	172	83	103	100	28
15	Male	67	180	91	111	115	28	43	Male	68	177	90	105	111	29
16	Female	67	172	64	99	104	22	44	Female	71	160	93	124	132	36
17	Female	73	180	90	112	115	28	45	Male	84	168	69			24
18	Male	75	190	97	119	115	27	46	Female	79	164	71	99	115	26
19	Female	72	165	81	102	115	30	47	Male	72	187	97	114	115	28
20	Male	67	175	105	123	118	34	48	Male	70	179	71	97	103	22
21	Male	72	195	95	115	114	25	49	Female	68	174	65	94	109	22
22	Male	68	177	84,5	105	106	27	50	Male	76	176	63	89	98	20
23	Male	75	173	75	98	99	25	51	Female	68	173	83	109	113	28
24	Male	65	195	93	109	107	25	52	Male	70	183	72	99	101	22
25	Female	65	178	62	92	103	20	53	Female	72	167	63	80	102	23
26	Male	67	181	85	97	102	26	54	Male	72	178	82	101	105	26
27	Male	65	189	88	107	105	25	55	Female	74	149	62	88	90	28
28	Female	74	160	80	100	110	31								

Table 1 - Demographics of all participants in the comparative user study.

Older participants								Younger reference group							
Nr.	Sex	Age (Years)	Stature (cm)	Weight (kg)	Waist circ. (cm)	Hip circ. (cm)	BMI	Nr.	Sex	Age (Years)	Stature (cm)	Weight (kg)	Waist circ. (cm)	Hip circ. (cm)	BMI
1	Male	80	182	85	103	114	26	1	Male	25	194	85	93	96	23
2	Male	72	182	118	131	134	36	2	Male	25	170	68	84	99	24
3	Male	75	185	107	112	118	31	3	Male	25	175	71	95	105	23
4	Male	81	182	74	88	97	22	4	Male	30	180	71	89	94	22
5	Male	78	176	83	99	105	27	5	Male	32	175	97	113	112	32
6	Male	76	178	99	119	111	31	6	Male	25	190	146	131	140	40
Average		77,0	180,8	94,3	108,7	113,2	28,8	Average		27,0	180,7	89,7	100,8	107,7	27,2
7	Female	77	165	62	71	103	23	7	Female	28	163	50	72	91	19
8	Female	76	161	43	72	85	17	8	Female	25	167	62	81	100	22
9	Female	72	165	78	102	109	29	9	Female	28	171	73	87	107	25
10	Female	77	170	85	90	100	29	10	Female	25	169	68	80	102	24
11	Female	74	157	63	87	102	25	11	Female	26	170	120	97	132	42
Average		75,2	163,6	66,2	84,4	99,8	24,6	Average		26,4	168,0	74,6	83,4	106,4	26,3

Appendix 7: Example of results from exhibition

DEFINED SEAT POSITION 1



Body data:

Paricipant: 38
Gender: Male
Age: 79
Stature: 178cm
Weigth: 72kg
Waist: 94cm
Hip: 107cm
BMI: 22,7
CVA: 41 degrees

Seat belt fit assesment:

Shoulder belt position
- On shoulder: Mid
- On abdomen: Low
Shoulder belt contact with body: Good
Lap belt contact to upper thigh: Good
Twisted seat belt: No

Measurements:

Shoulder belt angle: 40 degrees
Shoulder belt distance: 30mm
Lap belt angle: 26 degrees

CHOSEN SEAT POSITION

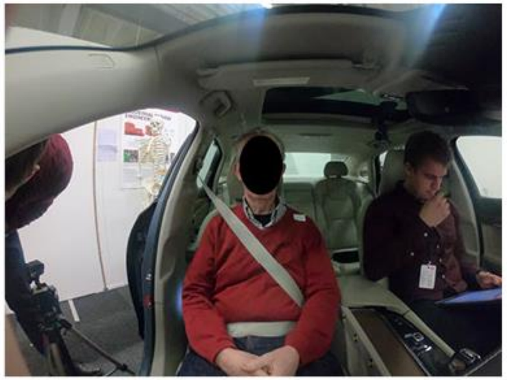
Seat belt fit assesment:

Shoulder belt position
- On shoulder: Mid
- On abdomen: Mid
Shoulder belt contact with body: Good
Lap belt contact to upper thigh: Good
ASIS position: Over
Overall seat belt fit: Good
Assessment of overall seat belt fit: Good
Twisted seat belt: No

Measurements:

Shoulder belt angle: 42 degrees
Shoulder belt distance: 23mm
Lap belt angle: 30 degrees

DEFINED SEAT POSITION 1



Body data:
Paricipant: 53
Gender: Male
Age: 72
Stature: 178cm
Weigth: 82kg
Waist: 101cm
Hip: 105cm
BMI: 25,9
CVA: 45 degrees

Seat belt fit assesment:
Shoulder belt position
- On shoulder: Tip
- On abdomen: High
Shoulder belt contact with body: Good
Lap belt contact to upper thigh: Good
Twisted seat belt: No

Measurements:
Shoulder belt angle: 42 degrees
Shoulder belt distance: 63mm
Lap belt angle: 27 degrees

CHOSEN SEAT POSITION

Seat belt fit assesment:
Shoulder belt position
- On shoulder: Tip
- On abdomen: High
Shoulder belt contact with body: Good
Lap belt contact to upper thigh: Good
ASIS position: On
Overall seat belt fit: Bad
Assessment of overall seat belt fit: Good
Twisted seat belt: No

Measurements:
Shoulder belt angle: 43 degrees
Shoulder belt distance: 74mm
Lap belt angle: 30 degrees

DEFINED SEAT POSITION 1

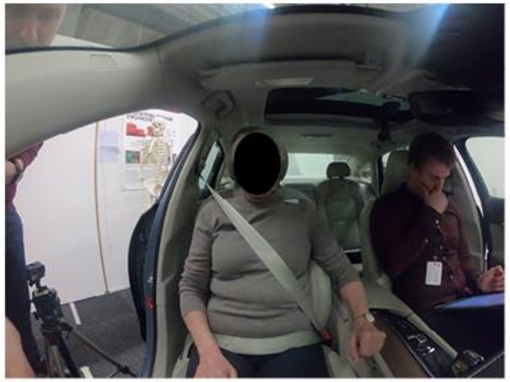


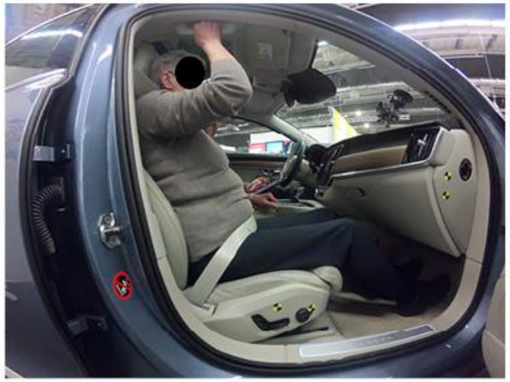
Body data:
Paricipant: 52
Gender: Female
Age: 72
Stature: 167cm
Weigth: 63kg
Waist: 80cm
Hip: 102cm
BMI: 22,6
CVA: 57 degrees

Seat belt fit assesment:
Shoulder belt position
- On shoulder: Mid
- On abdomen: Mid
Shoulder belt contact with body: Bad
Lap belt contact to upper thigh: Good
Twisted seat belt: No

Measurements:
Shoulder belt angle: 42 degrees
Shoulder belt distance: 64mm
Lap belt angle: 34 degrees

CHOSEN SEAT POSITION

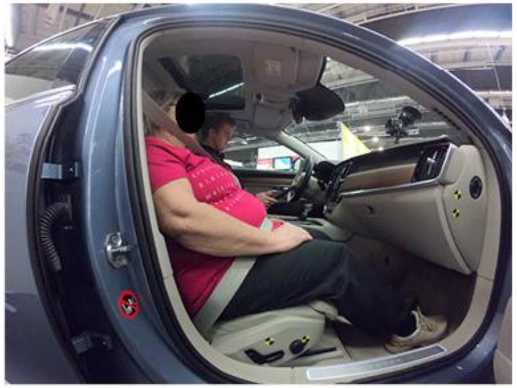




Seat belt fit assesment:
Shoulder belt position
- On shoulder: Mid
- On abdomen: High
Shoulder belt contact with body: Good
Lap belt contact to upper thigh: Good
ASIS position: Over
Overall seat belt fit: Good
Assessment of overall seat belt fit: Good
Twisted seat belt: No

Measurements:
Shoulder belt angle: 44 degrees
Shoulder belt distance: 72mm
Lap belt angle: 37 degrees

DEFINED SEAT POSITION 2



Body data:

Paricipant: 43
Gender: Female
Age: 71
Stature: 160cm
Weigth: 93kg
Waist: 124cm
Hip: 132cm
BMI: 36,3
CVA: 60 degrees

Seat belt fit assesment:

Shoulder belt position
- On shoulder: Mid
- On abdomen: High
Shoulder belt contact with body: Bad
Lap belt contact to upper thigh: Bad
Twisted seat belt: No

Measurements:

Shoulder belt angle: 50 degrees
Shoulder belt distance: 46mm
Lap belt angle: 34 degrees

CHOSEN SEAT POSITION

Seat belt fit assesment:

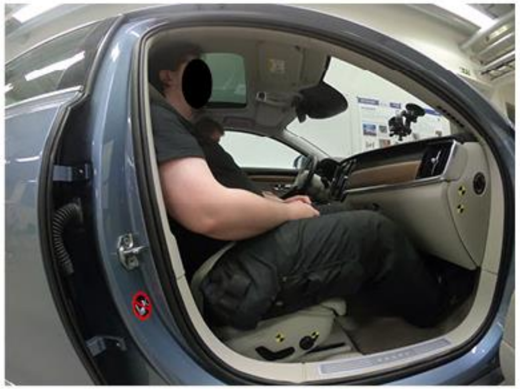
Shoulder belt position
- On shoulder: Neck
- On abdomen: High
Shoulder belt contact with body: Good
Lap belt contact to upper thigh: Good
ASIS position: Over
Overall seat belt fit: Bad
Assessment of overall seat belt fit: Bad
Twisted seat belt: No

Measurements:

Shoulder belt angle: 52 degrees
Shoulder belt distance: 15mm
Lap belt angle: 34 degrees

Appendix 8: Example of results from the comparative user study

DEFINED SEAT POSITION 1

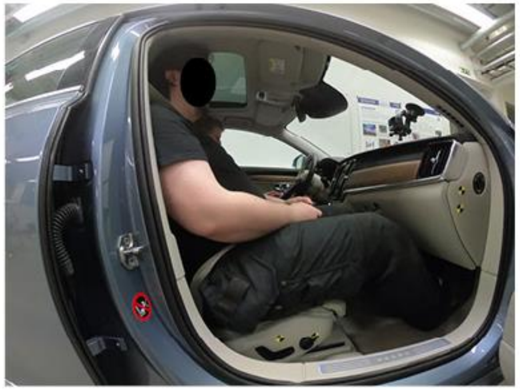


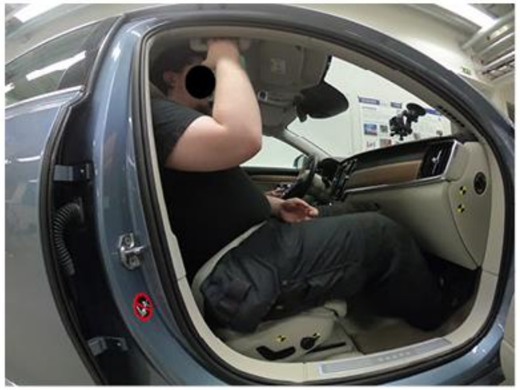
Body data:
Paricipant: 11
Gender: Male
Age: 25
Stature: 190cm
Weigth: 146kg
Waist: 131cm
Hip: 140cm
BMI: 40
CVA: 59 degrees

Seat belt fit assesment:
Shoulder belt position
- On shoulder: Mid
- On abdomen: High
Shoulder belt contact with body: Good
Lap belt contact to upper thigh: Good
Twisted seat belt: No

Measurements:
Shoulder belt angle: 53 degrees
Shoulder belt distance: 41mm
Lap belt angle: 32 degrees

CHOSEN SEAT POSITION

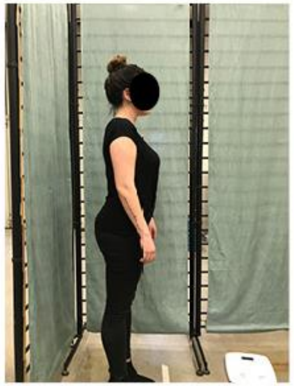


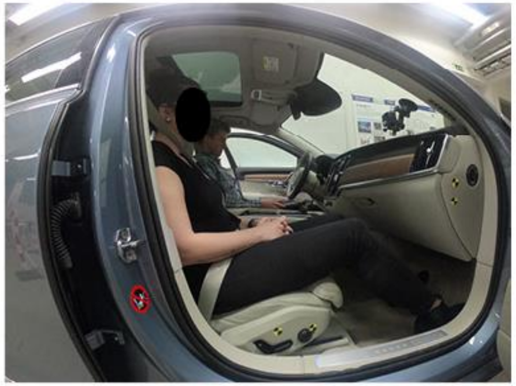


Seat belt fit assesment:
Shoulder belt position
- On shoulder: Mid
- On abdomen: High
Shoulder belt contact with body: Good
Lap belt contact to upper thigh: Good
ASIS position: Below
Overall seat belt fit: Good
Assessment of overall seat belt fit: Good
Twisted seat belt: No

Measurements:
Shoulder belt angle: 51 degrees
Shoulder belt distance: 54mm
Lap belt angle: 31 degrees

DEFINED SEAT POSITION 1





Body data:

Paricipant: 5
Gender: Female
Age: 28
Stature: 171cm
Weigth: 73kg
Waist: 87cm
Hip: 107cm
BMI: 25
CVA: 56 degrees

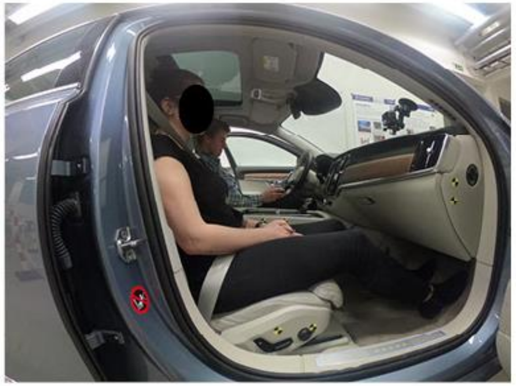
Seat belt fit assesment:

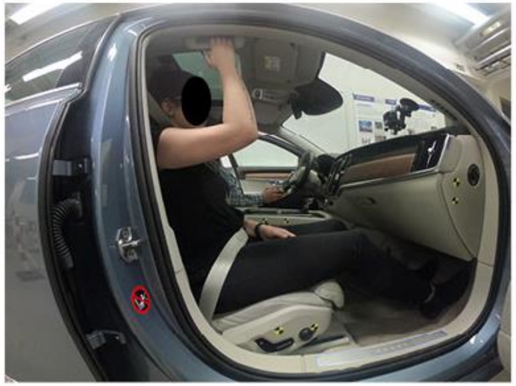
Shoulder belt position
- On shoulder: Mid
- On abdomen: Low
Shoulder belt contact with body: Good
Lap belt contact to upper thigh: Good
Twisted seat belt: No

Measurements:

Shoulder belt angle: 36 degrees
Shoulder belt distance: 83mm
Lap belt angle: 24 degrees

CHOSEN SEAT POSITION





Seat belt fit assesment:

Shoulder belt position
- On shoulder: Mid
- On abdomen: Low
Shoulder belt contact with body: Good
Lap belt contact to upper thigh: Good
ASIS position: Below
Overall seat belt fit: Good
Assessment of overall seat belt fit: Good
Twisted seat belt: No

Measurements:

Shoulder belt angle: 37 degrees
Shoulder belt distance: 93mm
Lap belt angle: 26 degrees

DEFINED SEAT POSITION 1

Body data:
Paricipant: 5
Gender: Male
Age: 75
Stature: 185cm
Weigth: 107kg
Waist: 112cm
Hip: 118cm
BMI: 31
CVA: 55 degrees

Seat belt fit assesment:
Shoulder belt position
- On shoulder: Mid
- On abdomen: High
Shoulder belt contact with body: Good
Lap belt contact to upper thigh: Good
Twisted seat belt: No

Measurements:
Shoulder belt angle: 47 degrees
Shoulder belt distance: 44mm
Lap belt angle: 32 degrees

CHOSEN SEAT POSITION

Seat belt fit assesment:
Shoulder belt position
- On shoulder: Mid
- On abdomen: High
Shoulder belt contact with body: Bad
Lap belt contact to upper thigh: Good
ASIS position: Below
Overall seat belt fit: Good
Assessment of overall seat belt fit: Bad
Twisted seat belt: No

Measurements:
Shoulder belt angle: 48 degrees
Shoulder belt distance: 31mm
Lap belt angle: 26 degrees

DEFINED SEAT POSITION 1

Body data:

Paricipant: 1
Gender: Female
Age: 77
Stature: 165cm
Weigth: 62kg
Waist: 71cm
Hip: 103cm
BMI: 22,8
CVA: 61 degrees

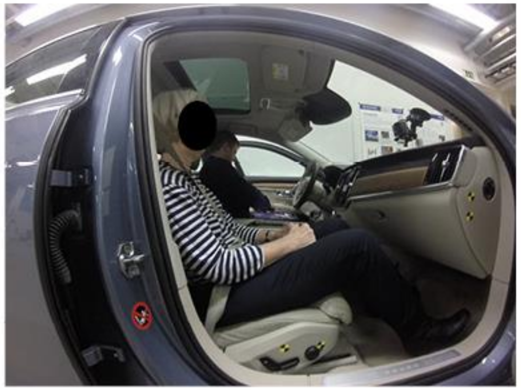
Seat belt fit assesment:

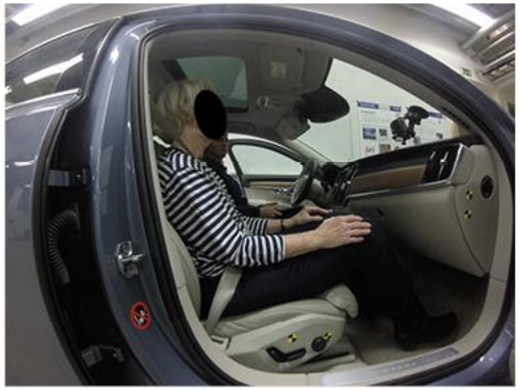
Shoulder belt position
- On shoulder: Neck
- On abdomen: Mid
Shoulder belt contact with body: Good
Lap belt contact to upper thigh: Bad
Twisted seat belt: Yes

Measurements:

Shoulder belt angle: 40 degrees
Shoulder belt distance: 28mm
Lap belt angle: 18 degrees

CHOSEN SEAT POSITION





Seat belt fit assesment:

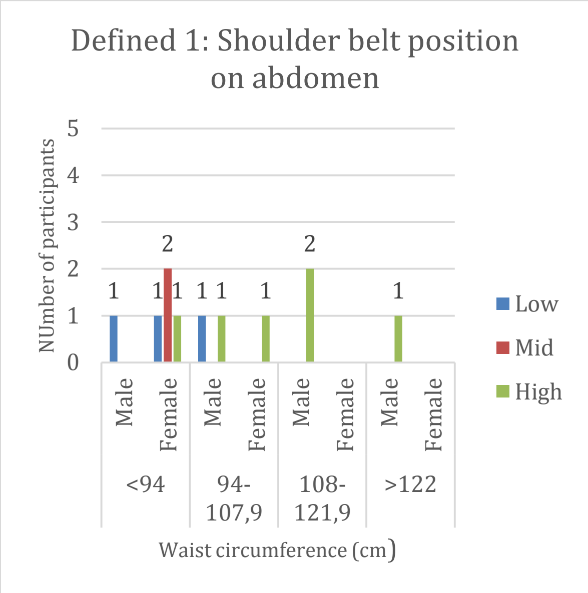
Shoulder belt position
- On shoulder: Neck
- On abdomen: Mid
Shoulder belt contact with body: Good
Lap belt contact to upper thigh: Bad
ASIS position: Below
Overall seat belt fit: Bad
Assessment of overall seat belt fit: Good
Twisted seat belt: Yes

Measurements:

Shoulder belt angle: 37 degrees
Shoulder belt distance: 53mm
Lap belt angle: 24 degrees

Appendix 9: Result graphs from comparative user study

1. Shoulder belt position in relation to abdomen compared to waist and hip circumference.



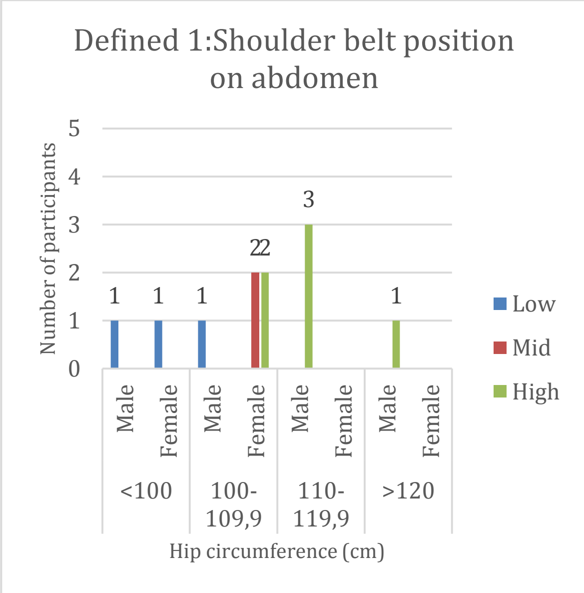


Figure 9.1 & 9.2 – Shoulder belt position on abdomen compared to waist and hip circumference, in defined seat position 1.

2. Shoulder belt angle and distance compared to stature.

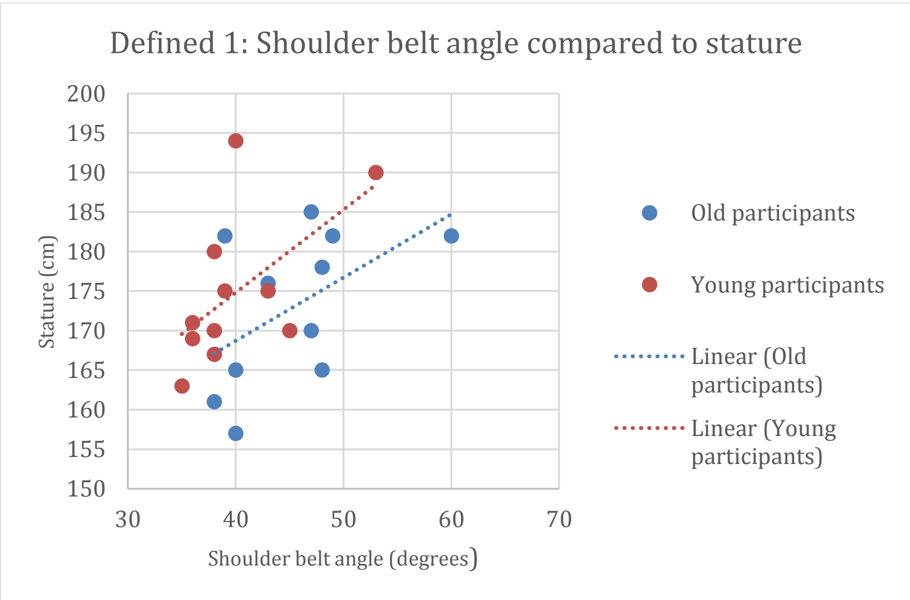


Figure 9.3 – Shoulder belt angle compared to stature among young and old participants, in defined seat position 1.

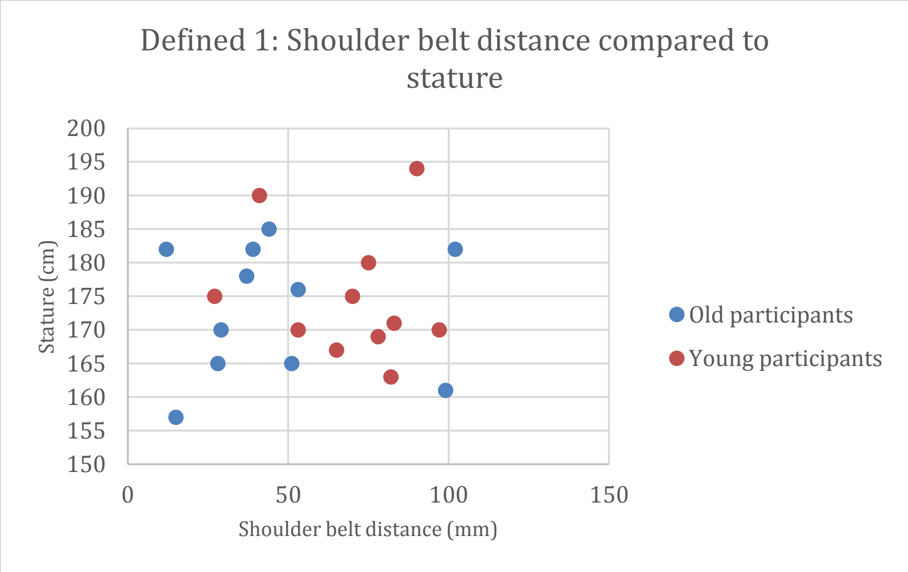


Figure 9.4 – Shoulder belt distance compared to stature among young and old participants, in defined seat position 1.

3. Shoulder belt angle compared to waist and hip circumference

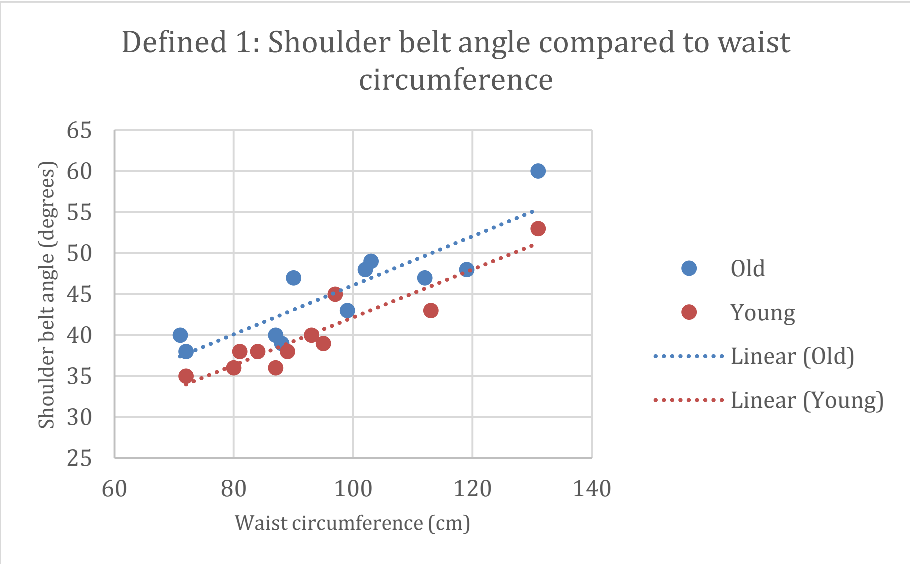


Figure 9.5 – Shoulder belt angle compared to waist circumference among young and old participants, in defined seat position 1.

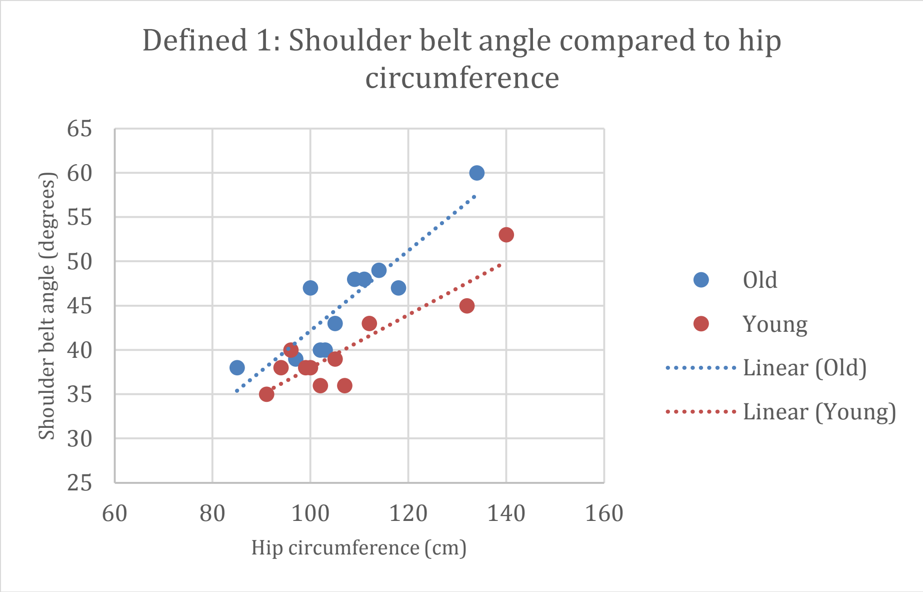


Figure 9.6 – Shoulder belt angle compared to hip circumference among young and old participants, in defined seat position 1.

4. Shoulder belt distance compared to waist and hip circumference

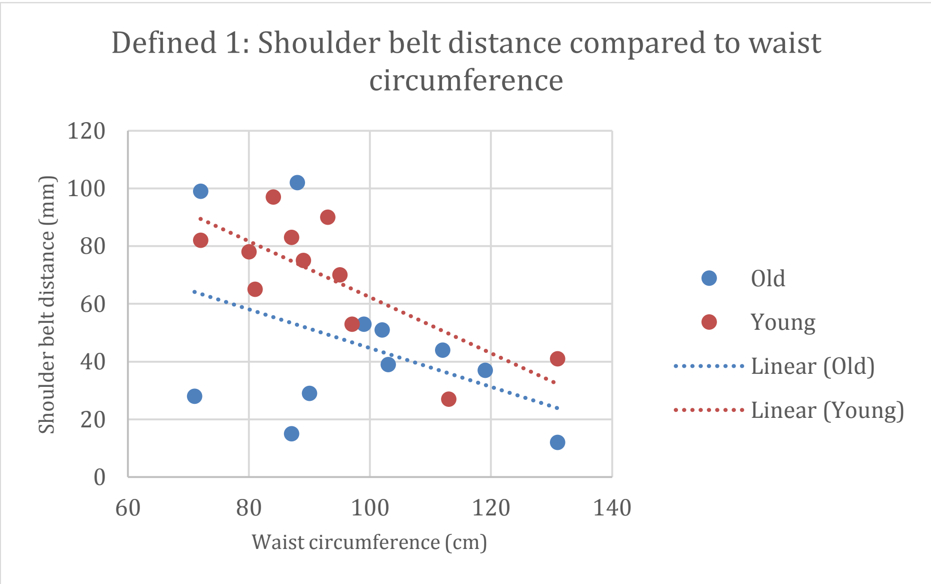


Figure 9.7 – Shoulder belt distance compared to waist circumference among young and old participants, in defined seat position 1.

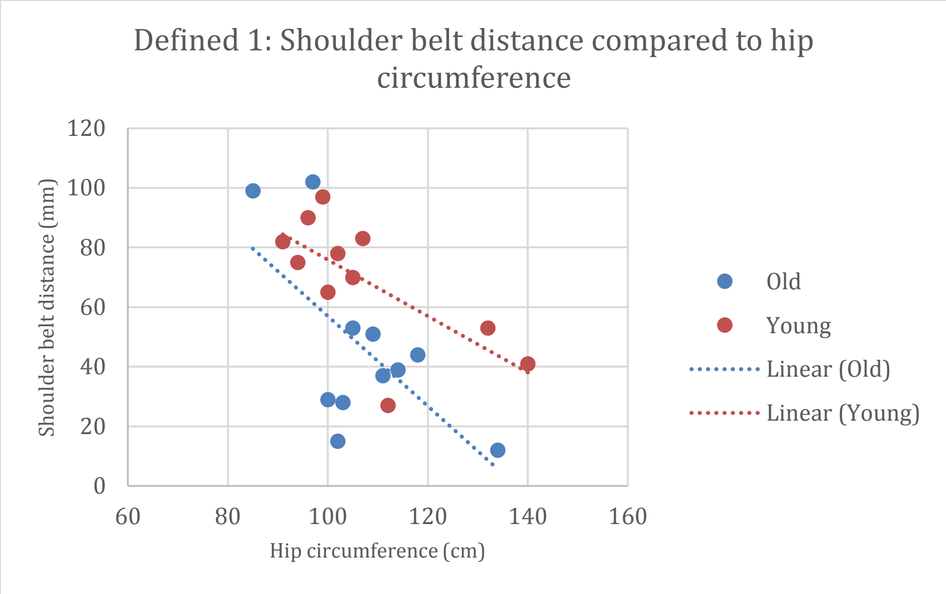


Figure 9.8 – Shoulder belt distance compared to hip circumference among young and old participants, in defined seat position 1.

5. Lap belt angle compared to waist and hip circumference

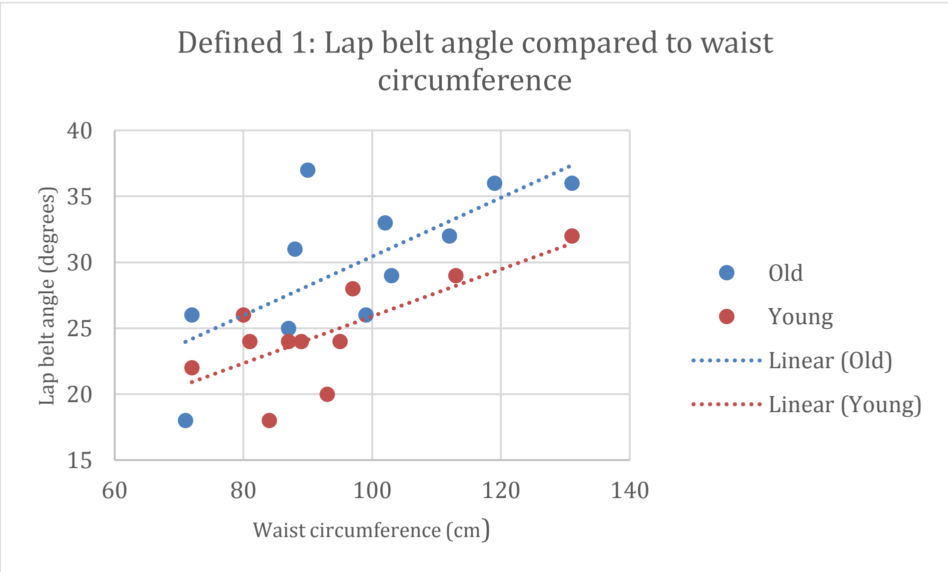


Figure 9.9 – Lap belt angle compared to waist circumference among young and old participants, in defined seat position 1.

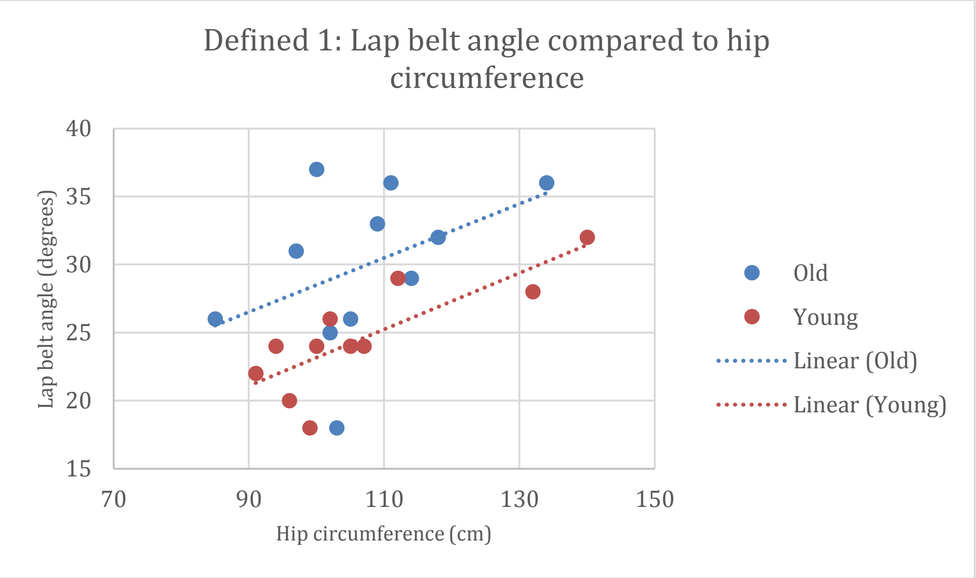


Figure 9.10 – Lap belt angle compared to hip circumference among young and old participants, in defined seat position 1.

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