Literature Review of Sitting Postures and Belt Fit in Passenger Vehicles

Melina Makris, PhD Student

September 19, 2022

Department of Industrial and Materials Science | Division of Design & Human Factors
Chalmers University of Technology

Car passenger Safety – To the next level

Abstract

To ensure the protection of all occupants in various accident scenarios, research is needed to understand how people sit, why they adopt certain sitting postures, and how these postures affect seat belt fit. A challenge in this field is establishing suitable methods for measuring and defining sitting postures and belt fit that produce results representative of real-world conditions. This literature review provides an overview of existing research on sitting posture and seat belt fit in passenger vehicles. It examines the methods used to measure and quantify sitting postures and belt fit, as well as the factors influencing them. The aim is to enhance knowledge and understanding in this area and to identify potential research gaps that can guide future studies. The review shows that both stationary and driving studies are frequently conducted methods, employing qualitative and quantitative approaches that collect subjective and objective data. However, a notable research gap exists regarding the comparison between stationary and driving studies and the type of results each approach produces. Furthermore, limited research has explored the correlation between subjective and objective data, which could help explain why certain sitting postures and belt fits occur. The time aspect also plays a crucial role when studying sitting postures, yet no clear conclusions have been drawn about when shorter or longer study durations are sufficient to obtain valid results. In conclusion, comparing different time intervals and determining the most appropriate approach for specific research questions could support the design of more efficient studies that produce valid insights into sitting posture and seat belt fit.

Keywords: Sitting posture, Seat belt fit, Comfort Occupant safety, Passenger vehicles, Measurement methods, Stationary and driving studies, Subjective and objective data, Qualitative and Quantitative data

Literature Review of Sitting Postures and Belt Fit in Passenger Vehicles

Table of contents

1. Introduction

Car passengers may adapt a wide range of sitting postures when travelling in passenger cars. Occupants adapt various sitting postures to maintain a comfortable posture and to avoid discomfort. Moreover, the posture is also affected by factors such as time of the trip, vehicle interior, different activities, age and anthropometric measures, which also leads to varying beltfit. In addition, the use of small, handled devices such as smart phones and tablets is also increasing today, leading to an increased number of passengers using such devices while travelling, affecting the sitting posture. With the development of highly automated vehicles (HAVs), an even larger variation of activities and sitting postures is expected as the driver no longer will be required to active drive nor monitor the traffic situation.

Studies have concluded that the optimal belt fit occurs when the shoulder belt is passed over the mid-portion of the shoulder, whereas the lap belt is judged optimal when the belt is positioned below the anterior-superior iliac spine (ASIS) landmarks and in contact with the upper thigh (Reed et al. 2013). To enable protection of all occupants in different accident scenarios, research on factors influencing posture and belt fit is required. One of the challenges this research faces regards establishing suitable methods for measuring and defining sitting postures and beltfit with repeatable methods, which still yields results corresponding to the reality.

1.1 Purpose

This literature review provides an overview of research about sitting posture and seat belt fit in passenger cars, including methods for measuring sitting postures and belt fit, quantification of sitting posture and beltfit, and factors influencing sitting postures and belt fit. The purpose of the literature review is to increase the knowledge and understanding of sitting postures and belt fit in passenger vehicles and identify gaps, if any, in the research, to set a basis for further studies.

1.2 Research questions

RQ1: What methods are used to measure sitting posture and seat belt fit in passenger vehicles?
RQ2: Which results are generated by the different methods for measuring sitting posture and belt fit?
RQ3: Which are the gaps in the research about sitting postures and belt fit in passenger vehicles?

1.3 Literature review approach

The literature review was executed by manual searches and by using common search data bases such as Google Scholar, Web of Science and PubMed. The manual searches included publications of methods for assessing and measuring sitting postures and belt fit, as well as results regarding sitting postures and belt fit and the factors influencing these. Relevant references found in the selected publications were also investigated. The following combination of terms were searched for in the title, the keywords and the abstract; *sitting posture*, *seat position*, *seat belt fit or beltfit*, *seat belt detection or recognition*. The searches excluded publications published before year 2000.

The review is divided into two topics: postures and belt fit. The two topics include subcategories of methods for measuring postures and belt fit respectively, as well as results from studies of posture and belt fit respectively. The review includes research of both front and rear seat passengers, and the focus is on adults, but also includes older children. However, a few publications include studies of younger children, in order to not exclude valuable measurement methods used for this user group, which might be useful for studies with adult passengers as well.

2. Postures

This chapter describes the literature found on sitting postures in vehicles, including both methods for measuring postures and results from the different types of studies.

2.1 Methods for measuring sitting postures

There are several methods for measuring sitting postures in vehicles. Driving studies with video cameras attached inside the vehicle to video record occupants are common to study behavior and posture during driving. Such methods allow for observing more natural behaviors of passengers while in a moving car but comes with the challenge of collecting detailed hands-on measurements. Conversely, stationary studies in laboratory settings with mock-up vehicles is another way to study sitting postures, which enables hands-on measurements such as using rulers or 3D measurement tools to take specific measurements of reference points, nonetheless with the lack of a more natural driving situation corresponding to the real car usage.

2.1.1 Driving studies

Driving studies investigating sitting postures may collect both subjective data such as interviews and questionaries of participants experiences, as well as objective data consisting of video recordings. By combining objective and subjective methods, valuable information regarding both posture, behavior and experience is provided. There are two main types of driving studies: field operational test (FOT) and naturalistic driving study (NDS). In NDS, video cameras and other data collecting equipment are discreetly installed in the vehicle to be less eye-catching to occupants, leading to a more natural sitting posture and behavior while video recorded. The vehicles in NDS are used by participants in their everyday normal driving for a larger amount of time. Such studies collect data on behavior in the neutral real-world setting to increase understanding of the relations between behavior and driving situation. In FOTs, vehicles are equipped with the system under investigation with recording equipment to collect data and carried out in a systematic way. They are often performed with a limited number of test drivers on closed test tracks, or on a pre-defined route in real traffic.

Naturalistic Driving Studies

Video recordings have been used in NDS to observe sitting postures in driving cars (Zhang et al. 2004, Paone et al. 2015, Reed et al. 2020, Reed et al. 2022). In two of these studies, video cameras were attached in the front seat passenger cabin of vehicles and reflective targets were attached on the seat to enable coding of posture and positions of front seat passengers (Reed et al. 2020) and second-row passengers (Reed et al. 2022). Passengers were recorded for two weeks while operating their vehicle as usual. For trips between 5-15 minutes, video frames from the first minute, approximately midpoint of trip and last minute of each trip were extracted. In the analysis, the video frame from the start and middle were made transparent and placed over the end video frame. For longer trips, additional frames were extracted with a maximum of 5 minutes between each frame, and for shorter trips a single midpoint frame was extracted from the middle of the trip. The seat was marked with seat reference markers, which enabled identification of changes in seat movements between trips. Changes were observed by extracting video frames from the start and middle each trip and overlaying transparencies of them on the end frame of the trip, to investigate whether marker locations had changed. A qualitative approach was used to code frames, consisting of a team of staff manually coding frames from the videos to identify postures and behaviors. Investigators trained to use example frames and in-depth coding coded posture and belt fit categorically by reference to example images. In addition, a video-based system was used to estimate front-passenger seat position and seat back angle. Regression analysis was performed to calculate relationships between reference points and seat position and seat back angle.

Another study investigated the usage rate of several sitting postures by conducting a survey including descriptions of 29 front passenger sitting postures and validated the responses with observations of video recordings from a NDS (Zhang et al 2004). The survey requested participants to estimate how often they adapted each of the defined 29 postures during a normal daily trip. The survey also collected information regarding anthropometric measures of the participants and factors which affect sitting posture such as vehicle type (coupe, SUV sedan, van, or pickup truck). Videos were recorded during highway driving from a tollbooth, using two cameras positioned to capture front passengers' posture as the vehicles approached the tollbooth. Based on the 29 defined postures, the observed postures were classified into four categories; comfort posture, relax posture, relief posture and rare posture, however, the authors do not describe the classification process.

Another NDS analyzed video data to quantify driver head pose, by training an open-source face detector to produce head pose (Paone et al. 2015). The study included over one million hours of video recordings of over 3100 volunteer drivers during a period of two years. In another NDS, children's head positions were quantified using a Kinect sensor which provided 3D motion capture at 1 Hz (Arbogast et al. 2016). In the study, a study vehicle was equipped with a data acquisition system to measure vehicle dynamics and a set of video cameras. Participant families used the study vehicle for two weeks. For each trip, rear seat children occupants' head position was manually identified via custom software from each Kinect color image. The 3D position of the head was thereafter extracted and categorized into seat position categories of left rear and center, and restraint type categories of forward-facing child restraint system, booster seat and seat belt.

Field Operational Tests

A FOT investigated children's sitting postures in two different booster designs during drive by using these methods, analyzing video recordings from inside the vehicle (Andersson et al. 2010). The duration of each sitting posture which participants adopted for more than one second during the drive was quantified. The sitting postures were systematically classified into categories differentiating the sagittal (fore-aft) from the lateral (left-right) sitting posture, and several head and torso positions in the x and y direction were defined. However, the study did not include observations of leg and arm positions. Similarly, two studies used a FOT approach to investigate children's sitting postures using these methods during on-road drives of 40 minutes and 1 hour, respectively (Jakobsson et al. 2011, Osvalder et al. 2013). In the analysis of the video recordings, sitting postures and belt positions were divided into categories. The first study categorized five sagittal torso postures, three sagittal head postures, three lateral sitting postures and four lateral head postures, whereas the second study also categorized lateral head posture in four categories. Both studies classified shoulder belt position into four categories: shoulder against neck, mid-shoulder, edge of shoulder and off-shoulder. The duration of each posture and shoulder belt position which was adopted for 1 second or more was assessed and categorized. The challenges of analyzing video recordings include distortions, since small movements may appear to be larger when the participant is closer to the camera.

Moreover, a FOT was conducted using a passenger sedan and a SUV to investigate occupant movements during crash avoidance maneuvers (Reed et al. 2021). Participants experienced two braking events, right and left-going lane changes and a turn-and-brake maneuver. The vehicle was equipped with internal measurement unit to record vehicle acceleration, and a novel motion-capture system using single Microsoft Kinect version-2 sensor to generate 3D motion data. The system included a head tracking accuracy comparable to optical motion capture systems, but did not require any markers on the subject, nor manual post-processing. Each participant's' head was 3D scanned before testing to fit the 3D data from the sensor to generate position and orientation.

Another study conducted a FOT and quantified the amplitude and duration of rotated head postures of drivers (Fice et al 2018). Participants' head positions relative to the car was recorded using inertial measurement units consisting of tri-axial accelerometers, magnetometers, and gyroscopes. Simultaneously, a test leader sitting in the passenger seat logged six head movements: bilateral shoulder and side mirror checks, looking at the rearview mirror, and looking at the front seat passenger while driving. The logged data was used with video recordings of participants to confirm logged data and further identify movements which the test leader had missed. Duration and amplitude of the six categories of head movements were compared between periods when the car was moving and when the car was standing still.

2.1.2 Stationary studies

Apart from driving studies performed in dynamic environments, sitting postures are also studied in laboratory environments in stationary vehicles or mock-ups. Such studies open for additional methods for measuring sitting postures, as it allows for more hands-on and more specific measurements.

A stationary study investigated the position of lower extremities in vehicles by setting up a mock-up consisting of a regular vehicle seat and a simplified dashboard, placed to represent the legroom of a sedan (Stanglmeier et al. 2021). Two different dashboard layouts of different heights were tested. To identify the posture, kinematic data of the lower extremities were collected using motion capture camera system using an adjusted lower body plug-in Gait marker setup. Participants of the study were asked to rate their level of agreement on whether they could easily perform the leg movements; ankle-on-knee and leg-crossing in the two different settings. Regression models were applied on the collected joint data to evaluate individual factors affecting movements and restrictions.

Another study performed in a stationary setting investigated how driver belt fit is affected by age, gender, stature, and BMI (Reed et al. 2013). A driver mockup was used where five sets of belt anchorage locations were tested on participants. Belt landmarks were measured with FARO Arm coordinate digitizer and additional measurements of bodies were taken in a hard seat and laser scanner. The shoulder belt fit was measured on the inboard edge of the belt at the height of the sternum top relative to midline, whereas the lap belt fit was measured on the top of belt at lateral position of ASIS with reference to ASIS.

Another study measured driving postures in a stationary laboratory mockup with nine package conditions (Reed et al. 2016). The conditions consisted of combinations of different seat heights and steering-wheel fore-aft position relative to the pedal reference point. For each seat height, the following conditions were fixed: the steering wheel height above the heel surface, steering wheel angle and accelerator pedal plane. The head restraint was removed from the seat to enable access to posterior landmarks and to prevent interference with drivers preferred head positions. Participants changed into test garments to facilitate access to body landmarks. Anthropometric measures were taken before they entered the vehicle mockup, as well as measurements in a hardback seat to enable measurement of the posterior spine and pelvis landmarks which were inaccessible in the driver mockup. Participants were instructed on how to adjust the seat and then the test conditions were presented in random order. For each condition, participants were asked to use all available seat adjustments to obtain a comfortable driving posture, and to buckle up. The test leader recorded the posture and component adjustments. For each test condition the locations of 38 landmarks were digitized, and the locations of internal joint centers were estimated by using statistical models. Landmark locations were initially calculated in the hard seat data, and thereafter repositioned in the vehicle seat data using an optimization algorithm. Posture-prediction models were developed for female and male drivers by developing a step-wise regression technique using variables such as age, body dimensions, vehicle package conditions and two-way interactions.

A study investigated child posture and belt fit in a range of booster configurations to quantify differences in posture and belt fit across booster designs (Jones et al. 2020). The study was performed in a laboratory setting, where measurements of children were taken in three laboratory seating conditions. The three seating conditions were distinguished by the length of the seat cushion, which was measured using a tool which was developed to approximate the SAE corresponding J2732 dimension. Six boosters were evaluated, as well as a condition with no booster. Standard anthropometric dimensions including stature, body weight and linear breadths and depths were collected. Participants wore test garments to facilitate access to landmarks. Body landmark locations were digitized using a FARO Arm coordinate measurement machine. In addition, each participant was measured while sitting in a laboratory hard seat which facilitated access to posterior landmarks on the spine and pelvis. The digitized landmarks were then used to calculate the three-dimensional position and orientation of the pelvis.

Another study used XSENS MVN Awinda, a non-invasive inertial measurement unit (IMU)-based 3D motion capture system to quantify body segment orientations and joint angles of children (Baker et al. 2021b). Children were evaluated on a custom fixture in a laboratory setting, with the aim to investigate children's postures on belt-positioning booster seats (BPBs). By using sensors, body regions of interest are not required to be within camera view. Moreover, the sensors provide continuous measurement. The study also used a 3D coordinate measurement system to quantify the instantaneous positions of anatomic, seatbelt, BPB and vehicle reference points.

A study examined a new method for visual quantification of body mass index by using videotape protocol and weight and height measurements (Park et al, 2018). Correlation with measured BMI and sensitivity, specificity, positive predictive value, and negative predictive value for overweight and obesity was calculated using SHAPECODER, a three-dimensional computer-based figure rating system on participants' videotaped image.

Stationary studies HAVs

In the future, highly automated vehicles may result in non-traditional seating configurations. Studies of preferences on seating positions in HAVs have therefore been conducted to investigate possible ways passengers' postures may adapt in such vehicles (Jorlöv et al. 2017, Yang et al. 2018, Reed et al. 2018, Reed et al. 2019 Koppel et al. 2019, Östling et al. 2019).

In one of these studies, an online survey was conducted where participants were asked participants to imagine travelling in a fully automated vehicle (FAV) and select 1 of 5 seating configurations (Figure

1) and 1 of 4 seating positions which they preferred (Koppel et al. 2019). Two studies investigated desires and attitudes towards seating configurations and sitting postures of highly automated cars by using a qualitative approach (Jorlöv et al. 2017) (Östling et al. 2019). Simplified physical vehicle environments were set up for each of the studies, using four chairs in an enclosed area simulating the car. Participants were asked to imagine different driving scenarios and position the chairs in their preferred configuration. In addition, the studies included a questionnaire and a structured interview. Data was collected by taking notes and photos as participants discussed and analyzed by conventional content analysis.

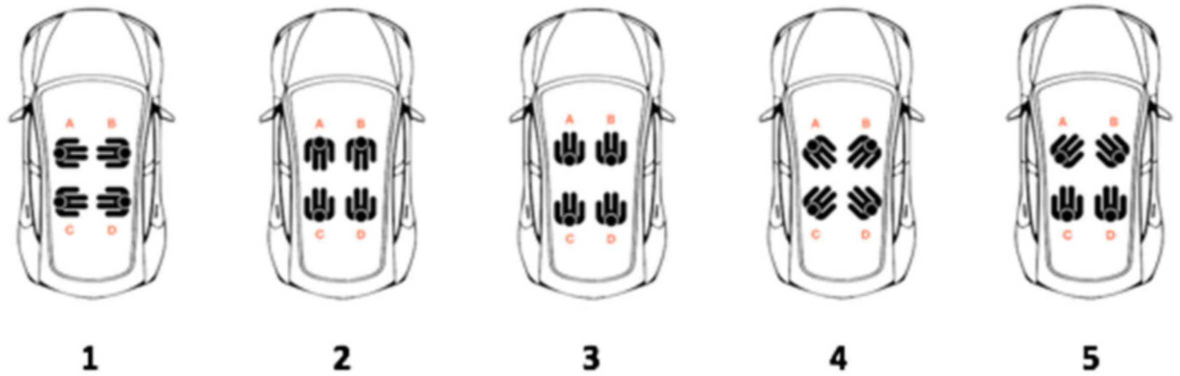

Figure 1. Five hypothetical FAV seating configurations (Koppel et al. 2019).

Moreover, studies performed in stationary environments using mock-ups in laboratory settings have been performed as an initial approach to investigate reclined sitting postures in HAVs (Yang et al. 2018, Reed et al. 2018, Reed et al. 2019, Stranglmeirer et al. 2020). One study tested seat pan angles of 20°, 30° and 40° with back rest angles of 145°, 155° and 165°, resulting in nine different combinations of reclined postures (Stranglmeirer et al. 2020). The sitting postures were evaluated subjectively by the participants who were asked to grade their level of agreement on the statement "*The current posture is suitable for sleeping"* in a 7-point Likert-scale. Moreover, objective measurements were taken of the pressure on the seat pan and backrest using two thin capacitive pressure mats on the mock-up seat. The pressure mats measured the total contact area, weight average pressure and interface pressure score. These measurements were taken to examine the biomechanical quality of sleeping postures in vehicles depending on seat properties.

Another study performed online surveys to collect data on non-driving related tasks (NDRTs) in manual driving and which postures were associated with these tasks in automated driving (Yang et al. 2018). In addition, the study conducted a stationary experiment in a mock-up seat in a laboratory setting. The seat pan was locked to 10°, whereas the seat backrest angle was adjustable from 0 to 68°. Participants adapted 10 different postures and seat adjustments, where the first four postures were pre-defined, whereas the other six were not specified but with specified NDRTs. Participants were interviewed regarding their choices of posture and whishes on interior. In each sitting posture, three photos were taken consisting of front, side and top view. A simplified 2D-model was constructed with torso, thigh, and knee angle. On top of the side view photos, ankle joint, calf, knee, thigh, hip point, torso and the C7 spinal segment were defined.

A third study also conducted a test in a vehicle mock-up and tested four different seat back angles; 23°, 33°, 43°, and 53° (Reed et al. 2018, Reed et al. 2019). The same vehicle mock-up was used in previous studies (Reed et al. 2013, Park et al. 2016). A seat belt assembly was mounted on customized fixtures to allow adjustment of belt anchorage locations. The posture was measured by locations of skeletal joint centers estimated from digital landmarks. The study used methods based on a previous study (Park et al. 2015) to orientate body landmarks. These measurement methods relied on palpation of the anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS).

Sensors and Machine Learning (ML)

Pressure sensors have been used to recognize sitting posture such as leaning patterns in stationary studies, outside vehicles (Xu et al 2013) (Ahmad 2017) (Liu et al. 2021). However, the average accuracy of these methods has not reached 90%. Another study investigated the potential value of associating pressure distribution data with reported discomfort (Porter et al. 2003), by collecting interface pressure data from 18 participants who each drove three different cars for 2 hours. Furthermore, the study measured participants' postural angles in each of the cars with a goniometer. Joints were marked using anatomical landmarks on the left side of the body (7th cervical vertebra, acromium, lateral epicondyle, ulnar styloid, greater trochanter, lateral condyle and lateral malleolus). The average of three readings of each angle, for each car was recorded. The measurements were taken in each of the cars while participants were seated in their nominal driving position.

Other research has used Kinect sensors for posture recognition (Zhang et al. 2014) (Chang et al 2014, Reed et al. 2018, 2019). In one of these studies, skeleton-based information obtained from Kinect camera was used to create features representing different body parts which were fed into Support Vector machine (SVM) learning algorithms to train for recognizing postures (Zhang et al. 2014). The system achieved an average accuracy of 99.14% in the testing of 22 trained postures. Another study then designed a posture recognition system to differentiate between proper and improper sitting posture to alert the user on adjusting their sitting posture (Chin et al 2019). The study utilized skeleton information from Kinect and compared the performance of SVM and Artificial neural network (ANN), where SVM was deemed as the better classifier. Another study developed models to recognize sitting postures using accelerometer readings from human spinal points through lightweight smartphones attached at body points, using a web camera to detect upper body points' location and distances (Estrada and Vea, 2017). The model was thereafter developed by training several classifiers. Another study collected head location data using a Microsoft Kinect v2 sensor and a methodology that fit 3D head scan data to the depth data acquired in the vehicle, with the aim to investigate head motions in the braking and lane change maneuvers (Reed et a. 2019). The data was collected while on a closed test track during a maneuver study. 12 participants sitting in the front passenger seat experienced two aggressive lane changes, a sharp right turn with hard braking and a second hard braking event.

Machine learning (ML) methods are commonly used to estimate sitting postures. Studies have used this technology to estimate body poses of passengers in vehicles, in both stationary and driving studies (Chun et al. 2019). Another study used a convolutional neural network (CNN) sitting posture recognition model based on pressure data. The model was developed to monitor and differentiate an improper sitting posture of human body in real time, with an accuracy of 95.5 %. Human pose estimation (HPE) can be divided in 2D and 3D methods (Gong et al. 2016). 2D HPE can be achieved using regression methods to build a mapping from input images to body joint coordinates by using deep learning regressors (Sun et al. 2017) (Luvizon et al. 2019). Body part detection is another 2D HPE method, which consists of localizing body parts by generating heatmaps of key points and assembling key points info whole body pose or skeleton (Cao et al. 2017) (Artacho et al 2020). These two methods can also be combined to increase estimation accuracy (Gong et al. 2016). HPE in 3D is a third method, which utilizes depth data to estimate poses (Martin et al. 2017). These methods eliminate illumination and variation in appearance which 2D methods must handle. Additional challenges of 2D HPE methods include complicated backgrounds, diverse clothing, and occlusions, whereas 3D HPE methods face challenges of posture information such as the demand of information on translations and rotations and depth uncertainties (Wang et al. 2021).

X-ray

Another method for measuring sitting posture is by using x-ray. A study measured skeletal alignment in sitting postures of a car seat to differentiate the postures by the following factors; age, gender and body type. The study was performed in a stationary setting, where participants were x-rayed while seated in an automotive seat and in a standing posture (Izimiyama et al. 2018). While seated, the seat back was inclined 24° and seat pan inclined 21.5°. X-ray images included subjects' head, cervical spine, thoracic spine, lumbar spine, pelvis, and legs. Based on analysis of the x-ray images, HBM models were created to represent individual differences by morphing the models.

2.2 Results of sitting postures

Based on the methods used for measuring sitting postures in driving and stationary studies respectively, this section describes the outcomes which they have resulted in. It provides an indication of what type of results and measurements of sitting posture may be achieved from different methods.

2.2.1 Results of sitting posture in driving studies

This section describes results of sitting postures in driving studies, including results found in both NDSs and FOTs.

Naturalistic Driving Studies

An NDS of 75 front seat passengers who were video recorded while operating their vehicle as usual for two weeks, found that the overall torso was in a non-nominal posture for more than 20% of the time: it was rotated left or right around 10% of the time and pitched forward in about 10% of frames (Reed et al 2020). The head lied against the headrest in 13% of frames. The feet were resting on the heels about 47 % of the time and resting on the soles with thighs lifted off the seat about 38% of the time. In about 6 % of the frames the legs were crossed. Sitting posture of adult second-row passengers were analyzed from the same data set (Reed et al. 2022). The results showed a low seat belt usage rate in the second row; 65% in non-ride hailing vehicles, and 32% in ride-hailing vehicles. Another finding was that non-nominal belt fit and posture may occur often in second row sitting positions. When it came to torso posture, it was tilted to the left or right in 16% and 11% of frames respectively, rather than neutrally positioned.

In another NDS, children's head positions were quantified using a Kinect sensor, capturing 3D head motion at 1 Hz of rear seat occupants (Arbogast et al. 2016). Data was collected from 18 families with 37 child occupants and resulted in 582 trips. The average age of the children was 45.6 months, and 51% were male. The study was able to quantify the head position for child occupants compare the motion between three different restraint types (forward-facing child restraint system, booster seat and seat belt).

Apart from findings regarding motion in the different restraint types, the study found that children sitting in the center rear seat in general demonstrated smaller range of head positions.

In a survey of estimated sitting postures in vehicles, 560 responders estimated how often they sat in 29 pre-defined sitting postures (Table 1) (Zhang et al 2004). The results of the survey were then validated with observations of video recordings of front passenger postures, captured by cameras attached in a tollbooth in a highway, during a day when traffic flow was 200-300 vehicles per hour. The images provided an estimation of the trend of likelihood of front passengers' posture, nevertheless it lacked details on lower extremities. In general, the results showed consistency trend between responders' estimations and video observations of sitting postures, despite the existence of discrepancy between results. Each of the 29 predefined postures were classified into four subcategories: comfort, relax, relief and rare. The comfort category included the postures 1, 23, 14, 15, and 20, The relax category included postures 13, 2, 12, 4, 22, 3, 24, 25, 9, 8, 5, and 21, the relief category included the postures 10, 28, 7, 26, 16, 17, 18, and 19 and the relief category included postures 6, 11, 27 and 29

The results showed that the likelihood of postures in the categories comfort and relax accounted for 95% of the total usage rate of all postures. However, the recorded postures from the tollbooth cannot be representative for an entire drive since they only captured the posture during the moment of driving under the tollbooth.

Table 1. Predefined postures which participants chose from when estimating their sitting postures.

1. Adult passenger in nominal sitting posture
2. Adult passenger sits upright on the rear portion of the cushion, with knee towards front at 30 degrees to the left
3. Adult passenger sits upright on the front portion of the cushion, with knee towards front at 30 degrees to the left
4. Adult passenger sits upright on the rear portion of the cushion, with knee towards front at 30 degrees to the right
5. Adult passenger sits upright on the front portion of the cushion, with knee towards front at 30 degrees to the right
6. Adult passenger sits upright with two legs crossed (Indian sitting)
7. Adult passenger sits against the seat back with both feet step on the edge of glove box
8. Adult passenger sits against the seat back with one foot (left or right) on the top of the instrument panel
9. Adult passenger sits against the seat back with both feet on the top of the instrument panel
10. Adult passenger sits with one leg (left or right) on the edge of the glove box
11. Adult passenger sits with two legs bent down on the knees (Japanese sitting)
12. Adult passenger sits with one foot placed under the other leg
13. Adult passenger sits with two knees towards outboard, each leg is at 45 degrees to the centerline of the body/ seat
14. Adult passenger sits leaning on the arm rest or center console at left side
15. Adult passenger sits leaning on the door sill at right side
16. Adult passenger sits upright outboard
17. Adult passenger sits upright inboard
18. Adult passenger sits against the seat back with two feet on the cushion of the seat
19. Adult passenger in nominal sitting posture with blanket or cloth on the seat

20. Adult passenger sits upright with one leg on the top of the other leg
21. Adult passenger sits upright with one leg on the top of the other leg, both knees facing right side at 30 degrees
22. Adult passenger sits upright with one leg on the top of the other leg, both knees facing left side at 30 degrees
23. Adult passenger sits upright with two lower legs crossed at the ankles
24. Adult passenger sits upright with two lower legs crossed at the ankles. Both knees are towards left side at 30 degrees
25. Adult passenger sits upright with two lower legs crossed at the ankles. Both knees are towards right side at 30 degrees
26. Adult passenger in half forward leaning posture
27. Adult passenger in fully forward leaning posture
28. Adult passenger in backward leaning posture with lower legs touching the glove box
29. Adult passenger sits upright on the front portion of the cushion

Field Operational Tests

A FOT investigating head movements of 20 drivers concluded that head movements were larger and of longer duration when standing still than when driving (Fice et al. 2018). Since the risk of acute whiplash injuries in rear-end impact increases from 23% when looking forward, to 36% when the head is turned (Jakobsson et al. 2008), these findings could possibly explain why drivers are more likely to suffer from whiplash injuries when hit from behind while their vehicle is stationary.

Another FOT was conducted using a passenger sedan and a SUV to investigate occupant movements during crash avoidance maneuvers (Reed et al. 2021). 90 participants of different anthropometrical measures experienced two braking events, right and left-going lane changes and a turn-and-brake maneuver. A qualitative review of video recordings from the studies showed that participants tended to maintain a constant relationship between head and torso, which consisted of a tendency to stiffen their neck during the maneuver event. During rebound, when the acceleration was removed, this movement sometimes lead to head pitching or rolling. Head center-of gravity (CG) excursions in the two braking events are shown in Figure 2 and Figure 3.

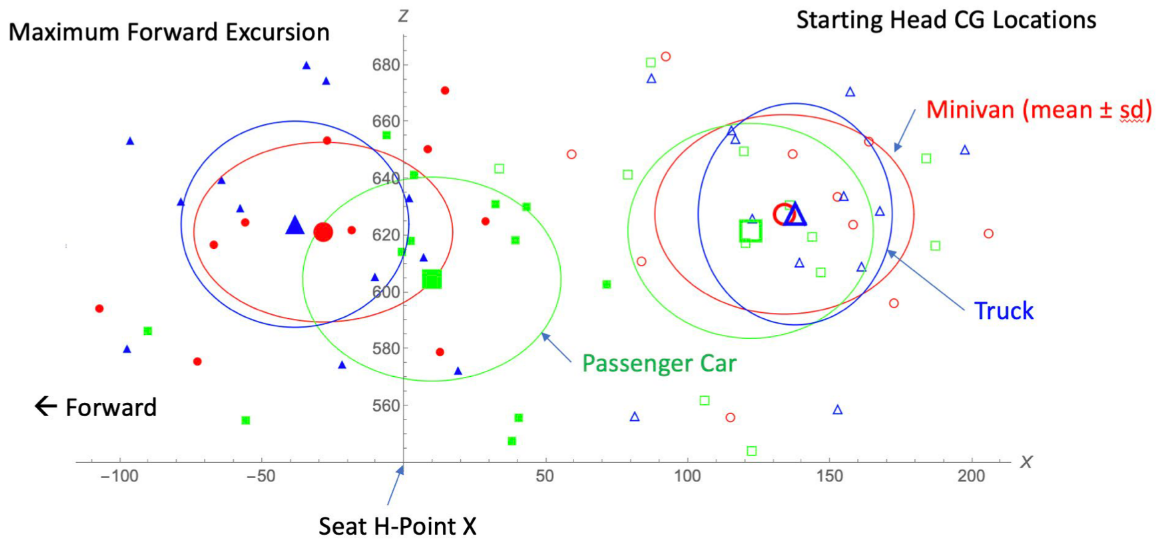

Figure 2. Head CG excursions in the first braking event in side view (mm). Head cg locations at the start of the event (open symbols) and at the point of maximum forward excursion (filled symbols) are shown for truck (triangle), minivan (circle), and passenger car (square). The mean for each vehicle is shown with larger symbols. The ellipses for each vehicle type have aces with length ± one standard deviation.

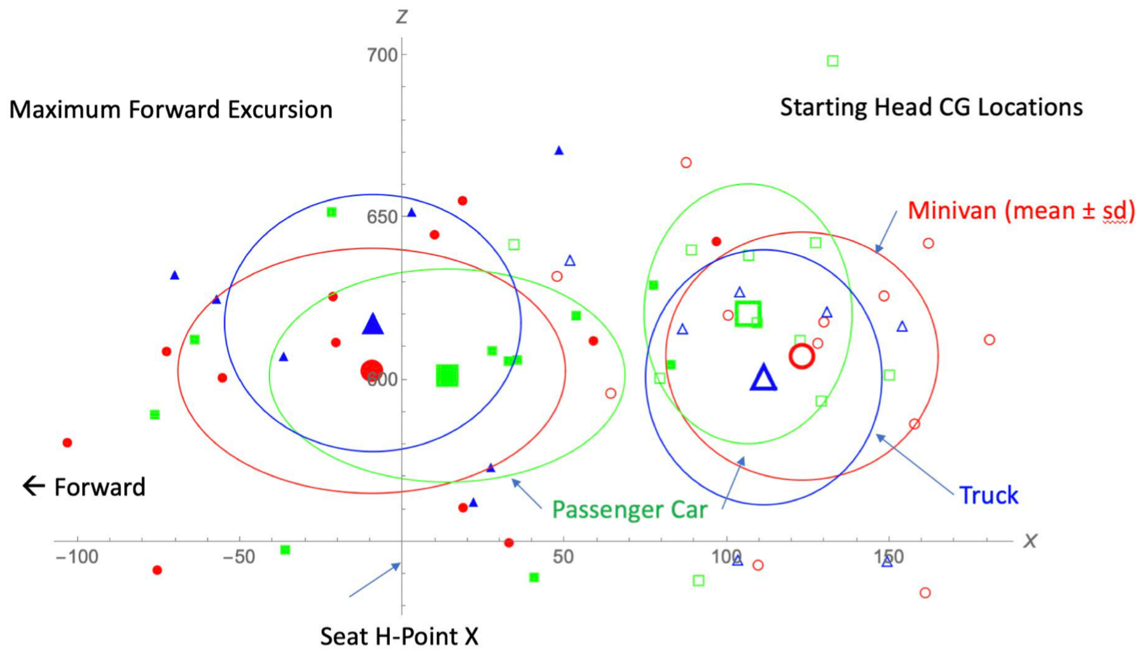

Figure 3. Head CG excursions in the second braking event in side view (mm). Head cg locations at the start of the event (open symbols) and at the point of maximum forward excursion (filled symbols) are shown for truck (triangle), minivan (circle), and passenger car (square). The mean for each vehicle is shown with larger symbols. The ellipses for each vehicle type have aces with length ± one standard deviation.

2.2.2 Results of sitting posture in stationary studies

A study which investigated the sitting posture of 75 participants in a stationary setting, where participants were x-rayed while seated in an automotive seat and in a standing posture found that sitting postures could be classified into two types; mild S-shaped and kyphosis (Izimiyama et al. 2018). By simulations of created HBM models based on the x-ray images, the study also found that the postures were influenced by BMI. Simulations showed that the more the pelvis was tilted rearward, the more the pelvic displacement and rotation increase, because of the lap belt which slide up and pushed the upper pelvis causing more rotation of the pelvis. The study also applied a normal distribution curve to the data obtained from x-ray to statistically infer the population, and selected the pelvic angles of 50th, 10th and 1th percentile from the distribution. Using the angles of lumbar spine, sacrum and pelvi from subjects with pelvic angles close to each represented percentiles, the skeletal alignment of THUMS ver.4AM50 was modified by giving a Prescribed-Motion on the vertebrae of the thorax spine, lumbar spine and pelvis. The study illustrated normal distribution of pelvic angle and the method to modify the skeletal alignment of THUMS (Figure 2).

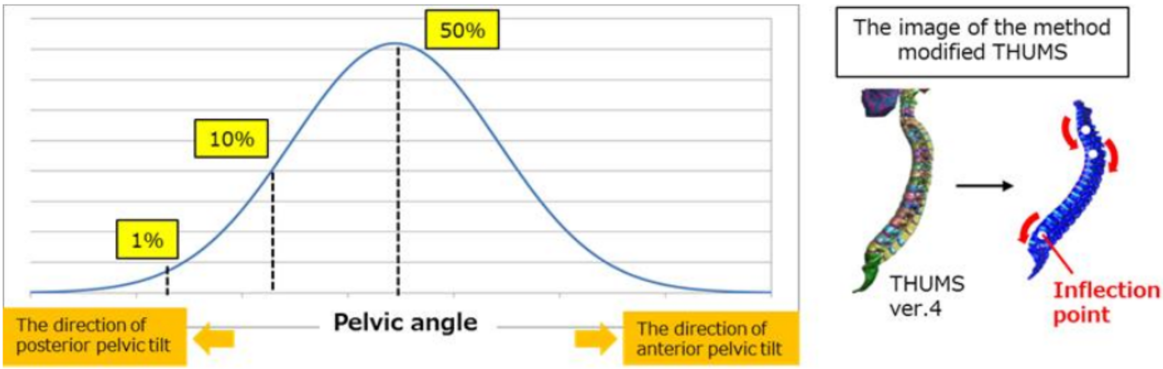

Figure 4. The study illustrated normal distribution of pelvic angle and the method to modify the skeletal alignment of THUMS.

A study with 30 participants investigated the position of lower extremities in a stationary setting in a mock-up seat, mimicking a sedan vehicle (Stanglmeier et al. 2021). Using motion capture camera system with an adjusted lower body plug-in Gait marker setup, the study found that the movement execution when performing an ankle-on-knee leg crossing movement is influenced by the provided legroom. A reduction of the legroom height resulted in an additional knee flexion and increased internal rotation of the knee joint.

Three studies investigated desires and attitudes towards sitting postures and seating configurations of highly automated cars (Jorlöv et al. 2017, Koppel et al. 2019, Östling et al. 2019). One of these three studies conducted a survey on preferred sitting postures and configurations in fully automated vehicles, which was completed by 502 participants (Koppel et al 2019). The other two studies used a qualitative approach and set up simplified physical vehicle environment using four chairs in an enclosed area simulating the car. Participants were asked to imagine different driving scenarios and test position the chairs in their preferred configuration. The studies were performed during an exhibition in Sweden, with 52 participants (Jorlöv et al. 2017) and in a shopping mall in China, with 100 participants (Östling et al. 2019). The studies found that users desire to recline the seat to a more relaxed position. Moreover, participants of the studies were positive towards extra restraints if that allowed for more flexibility in seating position.

A study in a mock-up seat in a stationary, laboratory setting examined the biomedical quality of sleeping postures in vehicles depending on angles on back rest and seat pan (Stranglmeirer et al. 2020). 23 male subjects participated, with a buttock-to-knee-length in the span of the 30-65th percentile of male Germans in 2008. Subjective measures of participants' preferences were collected and compared to measurements of pressure to the seat. The results showed that participants preferred configurations with backrest angle of 165° and seat pan angle of 20° or 30° for sleeping, whereas eight of the nine combinations of angles can be considered as suitable for sleeping. ANOVA measures however showed that interface pressure score significantly improved with increased seat pan angle, and that increased backrest angles result in better interface pressure score compared to smaller angles. The highest interface pressure score was observed for the combination of a 155° backrest angle with a 45° seat pan angle. Thus, the study recommended this combination for an in-vehicle sleeping position, due to the increased biomechanical quality.

Another stationary study conducted a mock-up seat fixed the seat pan angle to 10° and allowed for participants to adjust the backrest angle between 0° and 68° to take individually preferred positions (Yang et al. 2018). With 16 participants, the qualitative results showed that the most chosen posture (71.4%) in highly automated vehicle was a seat facing the driving direction, whereas the second ranked posture (10.3%) was the reclined posture facing the driving direction. Moreover, a study measured posture in a vehicle mock-up setting of a reclined seat (Reed et al. 2019). By characterizing posture of 24 participants by locations of skeletal joint centers estimated from palpation and digital landmarks, regression analysis could show that lumbar spine flexion increased with the reclination angle of the seat.

Another study examined a new method for visual quantification of body mass index by using videotape protocol and weight and height measurements of 242 child participants (Park et al, 2018). The study provided a new approach for assessing children's BMI by using a visual rating tool, which generated a correlation of r=0.89 between the generated BMI from recordings and measured BMI. Moreover, a study investigated driving postures in a stationary, laboratory setting using a mockup which was set up in nine different conditions (Reed et al. 2016). The 90 participants included both men and women or various sizes and ages. The study produced posture-prediction model for men and women to include effects of age, and enabled considerations of interactions between age, body dimensions and vehicle layout.

3. Belt fit

This chapter describes the literature found on methods for measuring and detecting belt fit, and what type of results that can be derived from different types of methods.

3.1 Methods for measuring belt fit

Many of the methods used for measuring sitting posture can be adjusted and used for measuring seat Belt fit. For instance, ML models can be used to measure and quantify seat belt fit as well. To avoid recurrence in this literature review, the ML methods for detecting seat belt fit will not be described in this section, as they have already been described for identifying sitting posture. Instead, the chapter will focus on other methods used in driving and stationary studies, which require different measurement approaches.

3.1.1 Driving studies

Methods for measuring belt fit in vehicles include the same type of driving studies as described in the previous chapter for measuring postures, namely NDSs and FOTs.

Naturalistic Driving Studies

Like methods investigating sitting postures, video recordings have been used in NDS to observe belt fit in driving cars (Reed et al. 2020, Reed et al. 2022). Video cameras were attached in the front seat passenger cabin of vehicles. The camera had a wide-angle lens, allowing it to capture the entire front row (Reed et al. 2020), whereas the view of the second row had some occlusion due to front seat occupants (Reed et al. 2022). The fit of the shoulder belt was manually coded by staff with the following categories of shoulder belt usage: no belt usage, middle of clavicle, lateral of clavicle, under arm, on neck, and forward of body.

Field Operational Tests

A FOT was conducted using a passenger sedan and a SUV to investigate occupant movements during crash avoidance maneuvers (Reed et al. 2021). Participants experienced two braking events, right and left-going lane changes and a turn-and-brake maneuver. Markers were attached to the seat belt webbing where it crossed the sternum, clavicle, and midline of the pelvis, and along the shoulder and lap belt at locations that were visible to the Kinect camera. Before the drive, while the vehicle was standing still, participant's posture and seat belt fit were recorded with a FARO arm while participants were asked to keep their head in an "alert" position. The optical markers enabled tracking of the seat belt in three-dimensions, using semi-automated methods. Belt tracking data can be used for tuning and validating computational models of occupant kinematics. A challenge with this method is however that targets can be obscured by participant's motion during the study.

Another FOT investigated the seat belt position of children in the rear seat of a passenger vehicle (Baker et al. 2018). The children were restrained with the seat belt in a booster cushion (BC) and on an integrated booster cushion (IBC), while a professional driver repeated sharp turns at 50 km/h. Video target points were placed on the upper sternum close to the suprasternal notch and pointed on the nasion and chin of each participant. A custom MATLAB software video tracking software was used to analyze kinematics of the nasion and upper sternum to evaluate shoulder belt engagement and position.

A FOT investigated older children's sitting postures, behaviors, and experiences. Several parameters were defined based on prior studies to describe initial posture (Osvalder et al. 2013). The initial position of the shoulder belt was classified into four categories; close to neck, mid-shoulder, far out, or slip-off and the lap belt was classified info three categories; high, mid, or low. In addition, belt-to-body interaction was visually assessed by evaluating whether a gap was present between the shoulder belt and lower torso. The study also quantified the duration of each belt position.

3.1.2 Stationary studies

A study conducted a test in a vehicle mock-up and tested four different seat back angles; 23°, 33°, 43°, and 53° (Reed et al. 2018, Reed et al. 2019). The lap belt fit was quantified by the fore-aft and vertical location of the upper and rearward margin of the lap portion of the belt at the lateral location o cation of the anterior-superior iliac spine (ASIS) landmarks on the left and right side of the pelvis. The shoulder belt fit was quantified by the lateral location of the inboard edge of the shoulder portion of the belt relative to the body midline at the height of the suprasternale landmarks.

Belt fit for children was analyzed in BPBs, by studying the gap between seatbelt and torso (Baker et al 2021a). A 3D coordinate measurement system (FARO Edge Arm, Lake Mary, Florida) was utilized to quantify positions of anatomic, seatbelt, BPB and vehicle reference points. The belt gap, its size, length and location and the belt fit on shoulder and pelvis were calculated using anatomic and seatbelt landmarks. Conventional belt fit measurements, shoulder belt score and lap belt score were calculated as described in previous studies (Reed et al. 2008).

A stationary study investigated the seat belt fit and comfort experience of older and younger front seat passengers by collecting photographs and measurements of the seat and seat belt position and posture (Bohman et al. 2019). The photographs captured both side and frontal view of seat belt, and an additional photo with the participant's arm raised for an improved view of the lap belt fit. The study started with an initial seat position which was the same for all participants, who sat down in this position and buckled up before photographs were taken. Thereafter each participant adjusted the seat to their preferred position and bucked up, whereas the photographing procedure took part again. The second photographs and measurements enabled quantification of the seat back angle, height, and seat rail position. The shoulder belt position was then categorized into four categories by manual observations of photographs; (1) Shoulder belt in contact or close to the neck, (2) positioned over mid-portion of the shoulder, (3) positioned on the shoulder edge, and (4) positioned off the shoulder. Similarly, the lap belt position was categorized into 3 categories: Low, mid, and high position in relation to the abdomen. A final measurement was taken of the distance from the suprasternal notch to the upper edge of the shoulder belt, along with the vertical line. Lastly, structured interviews were conducted to collect participant's subjective experience of seat belt fit and comfort.

A study investigated child posture and belt fit in a range of booster configurations to quantify differences in posture and belt fit across booster designs (Jones et al. 2020). The study was performed in a laboratory setting, where measurements of children were taken in three laboratory seating conditions. The FARO Arm coordinate measurement machine was used to measure landmarks on the seat belt and collect streams of data to define the belt path. The seat belt measurements were taken on the top and bottom of the lap belt at the lateral location of the left and right ASIS, and on the belt where it crossed over the sternum and clavicle.

A comparison of three-point belt fit between humans and Hybrid-III anthropometric test devices was performed in a stationary study, using a driver mockup (Park et al. 2021). Lap and shoulder belt fits were measured for small female and mid-sized male Hybrid-III ATDs in a laboratory mockup of a sedan, with a range of various lower and upper belt anchorage locations. The study allowed participants to position the seat belt comfortably, regardless of whether the position was optimal or not. Digitized reference marks on the ATDs were used to track the position of the pelvis bone ASIS points.

X-ray

Studies have also used x-ray images to measure the initial position of lap belt (Izimiyama 2020). By using x-ray images of pelvic sizes, Human Body models (HBMs) were created representing three pelvic sizes: 90th percentile, 50th percentile and 10th percentile. HBMs representing flesh thickness of the same percentiles were also created by measuring 20 participants' pelvises using x-ray images. The HBMs were used to analyze the relationship between flesh thickness and initial position of lap belt, belt angle and middle-ASIS distance.

3.2 Results of belt fit

Based on the methods used for measuring belt fit driving and stationary studies respectively, this section describes the outcomes which they have resulted in. It provides an indication of what type of results and measurements of belt fit may be achieved from different methods.

3.2.1 Results of belt fit in driving studies

This section describes the literature fund on results of belt fit in driving studies, including NDSs and FOTs.

Naturalistic Driving Studies

In an NDS of front seat passengers who were video recorded while using their vehicle as usual for two weeks, the belt was worn in 97% of the frames (Reed et al. 2020). However, the shoulder belt was observed off the shoulder in 22 % of frames, whereas the lap belt was observed on the abdomen 12 % of the time. The observations were approximately independent, meaning that non-ideal belt fit occurred more than 35% of the time. Sitting posture of adult second-row passengers were analyzed from the same data set (Reed et al. 2022). The results showed a low usage rate of seat belt in the second-row, especially in ride-hailing vehicles. Moreover, non-nominal belt fit and posture may occur often in second-row sitting positions. It was also more likely that the torso was tilted away from the belt. Nevertheless, non-neutral torso postures were not necessarily associated with poor shoulder belt fit, as the belt may still have remained on the shoulder.

Field Operational Tests

A driving study investigated the seat belt position of children in a booster cushion and in an integrated booster cushion in the rear seat of a passenger vehicle while a professional driver repeated sharp turns at 50 km/h (Baker et al. 2018). Using video target points placed on the upper sternum close to the suprasternal notch, a custom MATLAB software video tracking software was used to analyze kinematics of the nasion and upper sternum to evaluate shoulder belt engagement and position. It was found that children with less initial shoulder belt contact with torso moved laterally behind the belt. This resulted in straighter seat belt paths and outboard motion of the SB on the shoulder. In cases where more of the shoulder belt had initial contact with the torso, children tended to engage more with the shoulder belt causing the seat belt path to curve, leading to a less inboard head displacement and less outboard motion of the shoulder belt (Baker et al 2018).

3.2.2 Results of belt fit in stationary studies

A study measuring belt fit was performed in a stationary vehicle in a lab environment with 50 child participants (Baker et al. 2021a). By measuring the belt fit using a 3D coordinate measurement system, it was found that there were no strong correlations between conventional belt fit metrics and belt gap.

A stationary study investigating seat belt fit and comfort experience of older and younger front seat passengers by collecting photographs and measurements of the seat and seat belt position and posture (Bohman et al. 2019). The study found a wide range of the seat belt positions regardless of age. Passengers with higher BMI positioned the lap belt on higher up on the abdomen compared to participants with lower BMI, resulting in the shoulder belt closer to the neck. Participants with a smaller carniovertebral angle (CVA) (angle between the horizontal line passing through C7 and a line extending from the tragus of the ear) placed the shoulder belt closer to the suprasternal notch, compared to participants with higher CVA, resulting in the shoulder belt being placed closer to the throat. Older participants were less aware of safety concerns related to belt fit compared to younger participants and showed a trend of nonoptimal belt fit. The following seat belt positions were associated with nonoptimal belt fit; shoulder belt placed on the shoulder, shoulder belt having contact with clavicle, lap belt placed on abdomen, and a twisted belt.

A stationary study investigated belt fit in reclined sitting posture in a vehicle mock-up with 24 participants (Reed et al. 2019). Results showed that on average, the belt was further rearward relative to the pelvis, with an increased backrest angle. Nevertheless, the vertical position was not significantly affected. Moreover, it was shown that BMI was the most dominant predictor, and higher BMI was associated with further forward and higher lap belt positions.

A comparison of three-point belt fit between humans and Hybrid-III anthropometric test devices was performed in a driver mockup (Park et al. 2021). Lap and shoulder belt fits were measured for small female and mid-sized male Hybrid-III ATDs in a laboratory mockup of a sedan, with a range of various lower and upper belt anchorage locations. Differences in lap and shoulder belt fits were quantified between the physical ATDs and regression predictions for participants of similar sizes in human driving postures.

Another study investigated how driver belt fit is affected by age, gender, stature, and BMI (Reed et al. 2013) using a driver mockup. Five sets of belt anchorage locations were tested by 97 participants with a wide range of age and body size. Belt landmarks were measured with FARO Arm coordinate digitizer and additional measurements of bodies were taken in a a hardseat and laser scanner. The study provided conclusions on obesity, age, gender and lap belt anchorage locations. It was shown that obesity strongly affects the lap belt routing, and it was found that on average, an obese person places the belt above the pelvis, 61 mm forward of the ASIS. Age had a smaller effect on belt routing than BMI across the population range, whereas gender did not have a significant effect after accounting for stature. Lastly, lap belt anchorage locations were shown to have much smaller effects than driver factors. The effects of BMI on lap belt fit did not differ significantly for short or tall, men or women nor old and young. Moreover, the shoulder belt fit was strongly affected by D-ring location and body size.

X-ray images of 111 volunteers' pelvic sizes were used to create HBMs representing 90th percentile, 50th percentile and 10th percentile (Izimiyama et al. 2020). The study also analyzed flesh thickness, lap belt position and initial lap belt position of 20 participants with BMIs of 25 kg/m^2, 30 kg/m^2 and 35 kg/m^2. Calculations based on these HBM models showed that the amount of lap seatbelt sliding up over the ilium may increase with smaller pelvic size. Moreover, trends were identified regarding the correlation between BMI and initial position of lap belt, belt angle and middle-ASIS distance. Results from the simulations also showed that the lap belt path of HBMs with increased BMIs was longer and of smaller angle.

4. Synthesis

To provide an overview of the different methods for measuring sitting posture and belt fit, a summary of data collection methods, study approaches and results which may be obtained in stationary and driving studies is presented (Table 2).

TABLE 2. OVERVIEW OF METHODS FOR MEASURING SITTING POSTURE AND BELT FIT

Type of study	Data collection methods (objective/subjective)	Study approach (qualitative/kative)	Results
Naturalistic Driving Studies	Video recordings of posture and seat belt from cameras attached inside the vehicle Usage of reflective targets attached on the seats to enable coding of posture and seat position Video recordings from outside vehicle, eg. from a toll booth Enables posture and seat belt estimation by applying ML models and CNN (also possible for FOTs) Semi-objective data such as questionnaires before study, to collect demographic information, travel patterns, driving behaviour etc.	Postures from video frames may be manually coded and quantified by a team of staff (qualitative approach) Quantification of body part positions using Kinect sensors Seat position and back angle may be estimated by video-based systems (also possible in FOTs) Regression analysis to calculate relationships between reference points of seat position and seat back angle.	Video data, qualitative evaluation of posture and seat position. Quantification of postures and belt fit Tendencies of posture and beltfit and relationships between these Identification of when certain posture and/or belt fit occurs.
Field Operational Tests	Enables measurements of head movements by recording 3D head angular position relative to the car using inertial measurement units. Possibility to 3D scan participant's body before testing to fit 3D data from sensors to generate position and orientation.	Test leader inside vehicle may observe and log body part movements, and video recordings can be used to identify movements which the test leader misses.	Video data, qualitative evaluation of posture and seat position. Quantification of postures and belt fit

	Enables usage of measurement equipment attached to participants, such as reflective targets Enables recording of body parts' positions using inertial measurement units such as tri-axial accelerometers, magnetometers, and gyroscopes. Subjective data collection such as interviews Semi-objective data such as questionnaires	Video tracking software may be used to analyse kinematics to evaluate shoulder belt engagement and position (also possible in NDSs)	Tendencies of posture and beltfit and relationships between these Subjective measures of participants' experiences
Stationary studies	Enables collection of kinematic data of body parts using motion capture camera system, using an adjusted lower body plug-in Gait marker setup Enables posture recognition using Kinect sensors Enables posture and seat belt estimation by applying ML models and CNN Enables collection of pressure data on seat pan and backrest using pressure mats, further enabling examination of the biomechanical quality of postures in vehicles depending on seat properties Enables collection of 3D coordinates of body parts using FARO arm Enables non-invasive inertial measurement unit (IMU)-based 3D motion capture system, such as XSENS MVN Awinda Enables collection of X-ray data to measure e.g. pelvis orientation Possibility to use measurement methods based on palpation (e.g. palpation of the anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS)), which further enable measurements of posture by using locations of skeletal joint centres estimated from digital landmarks. Subjective data collection such as interviews Semi-objective data such as questionnaires	Regression models applied on eg. joint data to evaluate individual factors affecting movements and restrictions Investigation of desires and attitudes by using a qualitative approach including questionnaires, interviews, and manual observation of participants in studies Belt tracking data can be used for tuning and validating computational models of occupant kinematics. Objective data from videos, FARO arm, XSENS, x-ray etc. may be utilized when developing human body models to simulate different scenarios Objective data from XSENS may be utilized to quantify body segment orientations and joint angles	Subjective measures of participants' preferences Facilitates comparison of different settings (e.g. seat back angles) Detailed objective data of body positions (e.g. x-ray data of pelvis)

5. Discussion

This review investigates the most relevant literature found on sitting postures and belt fit in passenger vehicles, to provide an overview of measurement methods for assessing these, as well as which type of results that can be obtained from different type of methods.

5.1 Discussion of driving studies

The literature presents several driving studies, including NDSs and FOTs. In NDSs, participants ride their vehicles in their usual way while being video recorded with cameras attached inside the vehicle, FOTs are systematic studies, as they are performed on a pre-defined route which all participants take. NDSs enable video data collection on passengers' sitting posture and belt fit. These studies result in hours long video recordings, including both shorter and longer without the influence of a present test leader, nor a Osvalder et al., 2013led test environment. Apart from the NDSs with cameras attached inside the vehicle, one study recorded sitting posture with video cameras attached on a highway tollbooth. On one hand, this method implies that participants may be even more natural in their driving, as when there is camera attached inside the vehicle which may distract them. On the other hand, recordings from a tollbooth are not representative of passengers' sitting postures during an entire drive. Here. the recorded posture and belt fit may be influenced by the tollbooths position, as more postures facing left were observed, which may be considered as a result of the tollbooth being located to the left.

FOTs also enable video data collection on passengers' sitting posture and belt fit, however with the possible influence of the specific testing situation which may affect the participants' behavior and sitting posture. On the contrary, this method is more repeatable and allows for controlling parameters, ensuring that participants experience as similar situations as possible.

Placing digital or manual targets on participants to enable calculating distances of key points requires palpation (tactual exploration) for identifying the desired key points on body landmarks. Palpating participants may be challenging due to the variability in skeletal bone shape and fat tissue. Moreover, as the targets often are attached on top of clothes, they may detach from the surface or move due to movement of the clothes rather than due to a changed posture of the participant. Additionally, when analyzing videos where target points have been used, occlusion is challenging to avoid as well as distortions, since small movements may seem larger when participants move closer to the camera. To achieve consistency when classifying postures or belt fits manually, analyses of videos are often performed using systematic procedures, where different categories of postures or belt fits are defined by a group of analysts and thereafter clearly described before coding. The strength of video recordings is that video can be recorded in driving studies and enable capturing a behavior of passengers which is closer to reality than in stationary studies. Instead, the challenges of this method concern measurement accuracy since it may be challenging to ensure high level of detail of manually placed targets, since targets attached on participants' clothes can move in a way which does not always correspond to the participants' body movements. Yet, targets can be attached directly on the skin and participants can be asked to wear test clothes with holes cut in the body regions where targets are attached, to enable visibility and avoid the moving during testing.

ML models have the flexibility of being applied for estimating postures and belt fit in both stationary and driving studies. One of the described ML models distinguished between proper and improper sitting, which could be considered usable in studies investigating sitting posture and beltfit. Nonetheless, a critical issue which remains is interpreting what constitutes a proper and improper sitting posture and lap belt fit. There are numerous models which can be applied on both 2D and 3D data, and they face different challenges. While 2D models may achieve high estimation accuracy of body pose detection 3D models still require more development until they reach higher accuracy, as they require more information on e.g. translations and rotations.

5.2 Discussion of stationary studies

Stationary studies allow for using the same methods as in driving studies, but also open for more detailed hands-on measurements as vehicles or mock-ups are standing still. Measurements using a FARO arm yield detailed information about coordinate positions of posture and belt fit. However, this tool can only be used in stationary studies in laboratory settings, which lack the natural behavior of passengers in a moving vehicle. Moreover, taking measurements with the FARO arm is time consuming and it is also inflexible for executing studies in more than one car simultaneously, as moving the arm between cars is time consuming. Similarly, x-ray has shown to yield a high level of details, which can be utilized for developing computational models to enable simulations on specific sitting postures. Moreover, the method enables identification of anthropometric measurements, which are of interest when investigating sitting posture and belt fit, for example detailed data on pelvis orientation. However, exposing participants to x-ray for research purposes may be challenging from an ethical perspective.

Both driving studies and stationary studies can be used together with subjective data collection regarding the participants' experiences and preferences. The literature shows usage of questionnaires and semi structured interviews to collect data on participants subjective experiences. When combining subjective and objective measures, valuable information can be found regarding reasons behind adaptation of certain sitting postures and belt positions. This combination is important for achieving a deeper understanding of participants' behaviors and the factors influencing their sitting posture and beltfit, and may be utilized in research aiming to improve safety and protection of all occupants in different accident scenarios.

There are several factors influencing belt fit. Studies have stated BMI to be the most important factor influencing lap belt fit and is associated with lengthier belt webbing regardless of seat position or height (Reed et al. 2012). Moreover, age and anthropometric measures such as height, weight and body constitution are influencing factors on sitting posture and beltfit.

Since the population of the world is increasing, and people live longer, the elderly population is also growing. In 2030, it is estimated that 25 % of the population will be over 65 years old (Roser, 2019). Today, older adults are healthier and travel more, increasing passenger transportation (Schmocker et al., 2008; Clarke et al., 2009; Cole et al., 2010; Arai et al., 2011). In general, body proportions change when becoming older, as fat redistributes, muscles become weaker, posture becomes kyphotic and BMI increases. These changes result in altered posture when sitting (Wells et al., 2007) and can also lead to challenges with belt fit in cars.

6. Conclusions

This literature review provides an overview of research on sitting posture and seat belt fit in passenger cars, including methods for measuring sitting postures and belt fit, quantification of sitting posture and belt fit and factors influencing these. The conclusion is that methods for measuring sitting postures and belt fit include driving studies as well as studies in stationary vehicles. Driving studies range from FOTs to NDS. NDSs enable collection of objective data using video recordings to capture posture and seat belt fit in everyday vehicle usage, enabling analyzing quantification of postures as well as identifying tendencies and correlations between these, whereas FOTs also enable collection of subjective data in terms of interviews and questionaries. When it comes to stationary studies, they are often performed using mockups to mimic the vehicle interior. These studies range from more exploratory, qualitative approaches where subjective data is collected to investigate wishes and preferences, to more quantitative approaches with objective data collection methods, digitizing body, and belt landmarks to develop computational models of occupant kinematics. They enable parametric studies, where parameters of the vehicle geometry can be controlled.

The literature includes several stationary and driving studies, nevertheless, there is a research gap when it comes to comparison of stationary and driving studies respectively, and what type of results each study can yield. Research on the correlation between subjective and objective data is also lacking, which could improve the understanding of why certain sitting postures and belt fits occur. Moreover, the time aspect is crucial when investigating sitting postures. However, there is no conclusion regarding how much time is required for studying sitting postures in vehicles, nor which type of study to conduct to assess valid results. Comparing aspects of time and vehicle movement, and distinguishing which approach to use for which research question could be useful to conduct efficient studies which yield valid results of sitting posture and belt fit. To conclude, comparing time intervals and distinguishing which approach to use for which type of research question could be useful to conduct efficient studies which yield valid results of posture and belt fit.

6. References

Ahmad, J., Andersson, H. & Sidén, J. Sitting posture recognition using screen printed large area pressure sensors. 2017 Ieee Sensors, 2017. IEEE, 1-3.

Andersson, M., Bohman, K. & Osvalder, A.-L. 2010. Effect of Booster Seat Design on Children's Choice of Seating Positions During Naturalistic Riding. Annals of advances in automotive medicine. Association for the Advancement of Automotive Medicine. Annual Scientific Conference, 54, 171-180

Arai A, Mizuno Y, Arai Y. 2011. Implementation of municipal mobility support services for older people who have stopped driving in Japan. Public Health. 125(11):799–805.

Arbogast, K. B., Kim, J., Loeb, H., Kuo, J., Koppel, S., Bohman, K. & Charlton, J. L. 2016. Naturalistic driving study of rear seat child occupants: Quantification of head position using a Kinect™ sensor. *Traffic Injury Prevention,* 17**,** 168-174.

Artacho, B. & Savakis, A. Unipose: Unified human pose estimation in single images and videos. Proceedings of the IEEE/CVF conference on computer vision and pattern recognition, 2020. 7035-7044.

Baker, G., Stockman, I., Bohman, K., Jakobsson, L., Osvalder, A.-L., Svensson, M. & Wimmerstedt, M. 2018. Kinematics and shoulder belt engagement of children on belt-positioning boosters during evasive steering maneuvers. Traffic Injury Prevention, 19, S131-S138.

Baker, G. H., Mansfield, J. A., Hunter, R. L. & Bolte, J. H. 2021a. Evaluation of static belt fit and belt torso contact for children on belt-positioning booster seats. Traffic Injury Prevention, 22, S87-S92.

Baker, G.H, Mansfield, J.A, Hunter, R. L. & Bolte, J. H. 2021b. Application of an Inertial Unit (IMU)-based motion capture system for the quantification of child posture on belt-positioning booster seats. 19th Int. Conf. Protection

Bohman, K., Osvalder, A.-L., Ankartoft, R. & Alfredsson, S. 2019. A comparison of seat belt fit and comfort experience between older adults and younger front seat passengers in cars. Traffic injury prevention, 20, S7-S12.

Cao, Z., Simon, T., Wei, S.-E. & Sheikh, Y. Realtime multi-person 2d pose estimation using part affinity fields. Proceedings of the IEEE conference on computer vision and pattern recognition, 2017. 7291-7299.

Chang, C. W., Da Nian, M., Chen, Y. F., Chi, C. H. & Tao, C. W. Design of a Kinect sensor based posture recognition system. 2014 Tenth International Conference on Intelligent Information Hiding and Multimedia Signal Processing, 2014. IEEE, 856-859.

Chin, L., Eu, K. S., Tay, T. T., Teoh, C. Y. & Yap, K. M. A posture recognition model dedicated for differentiating between proper and improper sitting posture with kinect sensor. 2019 IEEE international symposium on haptic, audio and visual environments and games (HAVE), 2019. IEEE, 1-5.

Chun, S., Hamidi Ghalehjegh, N., Choi, J., Schwarz, C., Gaspar, J., Mcgehee, D. & Baek, S. NADS-Net: A Nimble Architecture for Driver and Seat Belt Detection via Convolutional Neural Networks. Proceedings of the IEEE/CVF International Conference on Computer Vision Workshops, 2019. 0-0.

Clarke P, Ailshire JA, Lantz P. 2009. Urban built environments and trajec- tories of mobility disability: findings from a national sample of com- munity-dwelling American adults (1986 2001). Soc Sci Med. 69:964–70.

Cole R, Burke M, Leslie E, Donald M, Owen N. 2010. Perceptions of representatives of public, private, and community sector institutions of the barriers and enablers for physically active transport. Transp Policy. 17(6):496–504

Estrada, J. & Vea, L. Sitting posture recognition for computer users using smartphones and a web camera. TENCON 2017 - 2017 IEEE Region 10 Conference, 5-8 Nov. 2017 2017. 1520-1525.

Fice, J. B., Blouin, J.-S. & Siegmund, G. P. 2018. Head postures during naturalistic driving. Traffic Injury Prevention, 19, 637-643.

Gong, W., Zhang, X., Gonzàlez, J., Sobral, A., Bouwmans, T., Tu, C. & Zahzah, E.-H. 2016. Human pose estimation from monocular images: A comprehensive survey. Sensors, 16, 1966.

Izumiyama, T., Nishida, N., Iwanaga, H., Chen, X., Ohgi, J., Asahi, R., Sugimoto, S. & Fukushima, M. Identification of Influential Factors for Seatbelt Kinematics in a Collision and Analysis of their Influence Degree to the Kinematics. IRCOBI conference, 2020. 456-469.

Izumiyama, T., Nishida, N., Iwanaga, H., Chen, X., Ohgi, J., Mori, K., Hayashi, T., Sakuramoto, I., Asahi, R. & Sugimoto, S. The analysis of an individual difference in human skeletal alignment in seated posture and occupant behavior using HBMs. Proceedings of the International Research Conference on the Biomechanics of Impact, IRCOBI, Athens, Greece, 12th September-14th September. IRC-18-84, 2018.

Jakobsson, L., Bohman, K., Stockman, I., Andersson, M. & Osvalder, A.-L. Older children's sitting postures when riding in the rear seat. Ircobi Conference, 2011. 14-16.

Jakobsson, L., Isaksson-Hellman, I. & Lindman, M. 2008. WHIPS (Volvo Cars' Whiplash Protection System)—The Development and Real-World Performance. Traffic Injury Prevention, 9, 600-605.

Jones, M. L., Ebert, S., Manary, M. A., Reed, M. P. & Klinich, K. D. 2020. Child posture and belt fit in a range of booster configurations. *International journal of environmental research and public health,* 17**,** 810.

Jorlöv, S., Bohman, K. & Larsson, A. Seating positions and activities in highly automated cars–a qualitative study of future automated driving scenarios. International research conference on the biomechanics of impact, 2017. 13-22.

Koppel S, Jiménez Octavio J, Bohman K, Logan D, Raphael W, Quintana Jimenez L, et al. Seating configuration and position preferences in fully automated vehicles. Traffic Inj Prev. 2019:1-7. doi: 10.1080/15389588.2019.1625336 PMID: 31246512.

Liu, C., Wu, J., Yi, M. & Li, Y. Research on sitting posture detection method based on flexible film pressure sensor. International Conference on Sensors and Instruments (ICSI 2021), 2021. International Society for Optics and Photonics, 1188706.

Liu, W., Guo, Y., Yang, J., Hu, Y. & Wei, D. Sitting posture recognition based on human body pressure and CNN. AIP Conference Proceedings, 2019. AIP Publishing LLC, 020093.

Luvizon, D. C., Tabia, H. & Picard, D. 2019. Human pose regression by combining indirect part detection and contextual information. Computers & Graphics, 85, 15-22.

Martin, M., Stuehmer, S., Voit, M. & Stiefelhagen, R. Real time driver body pose estimation for novel assistance systems. 2017 IEEE 20th International Conference on Intelligent Transportation Systems (ITSC), 16-19 Oct. 2017 2017. 1-7.

Osvalder, A.-L., Hansson, I., Stockman, I., Carlsson, A., Bohman, K. & Jakobsson, L. Older children's sitting postures, behaviour and comfort experience during ride–A comparison between an Integrated Booster Cushion and a high-back booster. Proceedings 2013 IRCOBI Conference, 11-13 September, Gothenburg, Sweden, 2013.

Paone, J., Bolme, D., Ferrell, R., Aykac, D. & Karnowski, T. Baseline face detection, head pose estimation, and coarse direction detection for facial data in the SHRP2 naturalistic driving study. 2015 IEEE Intelligent Vehicles Symposium (IV), 2015. IEEE, 174-179.

Park J, Ebert SM, Reed MP, Hallman JJ. 2015. Development of an opti- mization method for locating the pelvis in an automobile seat. Paper presented at: 6th International Conference on Applied Human Factors and Ergonomics, Las Vegas, Nevada.

Park J, Ebert SM, Reed MP, Hallman JJ. 2016. Statistical models for pre- dicting automobile driving postures for men and women including effects of age. Hum Factors. 58(2):261–78. 10.1177/0018720815610249

Park, B. K. D., Reed, M. P., Kaciroti, N., Love, M., Miller, A. L., Appugliese, D. P. & Lumeng, J. C. 2018. SHAPECODER: a new method for visual quantification of body mass index in young children. *Pediatric obesity,* 13**,** 88-93.

Park, B.-K. D., Jones, M. L., Ebert, S. & Reed, M. P. 2021. A parametric modeling of adult body shape in a supported seated posture including effects of age. *Ergonomics***,** 1-9.

Park, J., Ebert, S. M., Reed, M. P. & Hallman, J. J. 2016. A statistical model including age to predict passenger postures in the rear seats of automobiles. *Ergonomics,* 59**,** 796-805.

Porter, J. M., Gyi, D. E. & Tait, H. A. 2003. Interface pressure data and the prediction of driver discomfort in road trials. Applied ergonomics, 34, 207-214.

Reed MP, Ebert SM, Jones MLH, Park BD. Comparison across vehicles of passenger head kinematics in abrupt vehicle maneuvers.Traffic Inj Prev. 2019;20(sup2):S128-S132.

Reed MP, Ebert SM, Jones MLH, Park BD, Hallman JJ, Sherony R Passenger head kinematics in abrupt braking and lane change events. Traffic Inj Prev. 2018;19(sup2):S70-S77

Reed, M. P., Ebert, S. M. & Hallman, J. J. 2013. Effects of driver characteristics on seat belt fit. *Stapp car crash journal,* 57**,** 43-57.

Reed MP, Ebert-Hamilton S, Rupp J. 2012. Effects of obesity on seat belt fit. Traffic Inj Prev. 13(4):364–72

Reed, M. P., Ebert-Hamilton, S. M., Klinich, K. D., Manary, M. A. & Rupp, J. D. 2013. Effects of vehicle seat and belt geometry on belt fit for children with and without belt positioning booster seats. Accident Analysis & Prevention, 50, 512-522.

Reed, M. P., Ebert, S. M. & Jones, M. L. H. 2019. Posture and belt fit in reclined passenger seats. Traffic Injury Prevention, 20, S38-S42.

Reed, M. P., Ebert, S. M., Jones, M. H. & Park, B.-K. D. 2021. Occupant Dynamics During Crash Avoidance Maneuvers. United States. Department of Transportation. National Highway Traffic

Safety Administration

Reed, M. P., Ebert, S. M., Jones, M. L. & Hallman, J. J. 2020. Prevalence of non-nominal seat positions and postures among front-seat passengers. Traffic Injury prevention, 21, S7-S12.

Reed, M. P., Ebert, S. M., Jones, M. L. H. & Hallman, J. J. 2022. A naturalistic study of passenger seating position, posture, and restraint use in second-row seats. Traffic Injury Prevention, 1-6.

Roser M. 2019. Life expectancy. [accessed 2022 Jun 23]. https://ourworldindata.org/life-expectancy .

Schmocker JD, Quddus MA, Noland RB, Bell M. 2008. Mode choice of older and disabled people: a case study of shopping trips in London. J Transp Geogr. 16(4):257–67.

Stanglmeier, M. J., Paternoster, F. K., Paternoster, S., Bichler, R. J., Wagner, P.-O. & Schwirtz, A. 2020. Automated driving: A biomechanical approach for sleeping positions. Applied ergonomics, 86, 103103.

Stanglmeier, M. J., Schulte, F., Schauberger, G., Bichler, R. J., Schwirtz, A. & Paternoster, F. K. 2021. Effect of legroom proportions and individual factors for sitting with crossed legs: implications on the interior design of automated driving vehicles. Ergonomics, 64, 1393-1404.

Wang, J., Tan, S., Zhen, X., Xu, S., Zheng, F., He, Z. & Shao, L. 2021. Deep 3D human pose estimation: A review. Computer Vision and Image Understanding, 210, 103225.

Wells, JC, Treleaven, P, Cole, TJ. 2007. BMI compared with 3-dimen- sional body shape: the UK National Sizing Survey. Am J Clin Nutr. 85(2):419–425.

Xu, W., Huang, M.-C., Amini, N., He, L. & Sarrafzadeh, M. 2013. ecushion: A textile pressure sensor array design and calibration for sitting posture analysis. IEEE Sensors Journal, 13, 3926-3934.

Yang, Y., Klinkner, J. N. & Bengler, K. How will the driver sit in an automated vehicle?–The qualitative and quantitative descriptions of non-driving postures (NDPs) when non-driving-related-tasks (NDRTs) are conducted. Congress of the International Ergonomics Association, 2018. Springer, 409-420.

Zhang, L. L., Chen, L., Vertiz, A. & Balci, R. 2004. Survey of front passenger posture usage in passenger vehicles. SAE Technical Paper.

Zhang, Z., Liu, Y., Li, A. & Wang, M. A novel method for user-defined human posture recognition using Kinect. 2014 7th International Congress on image and signal processing, 2014. IEEE, 736-740.

Östling, M. & Larsson, A. Occupant activities and sitting positions in automated vehicles in China and Sweden. 26th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Eindhoven, Netherlands, 2019. 10-13.