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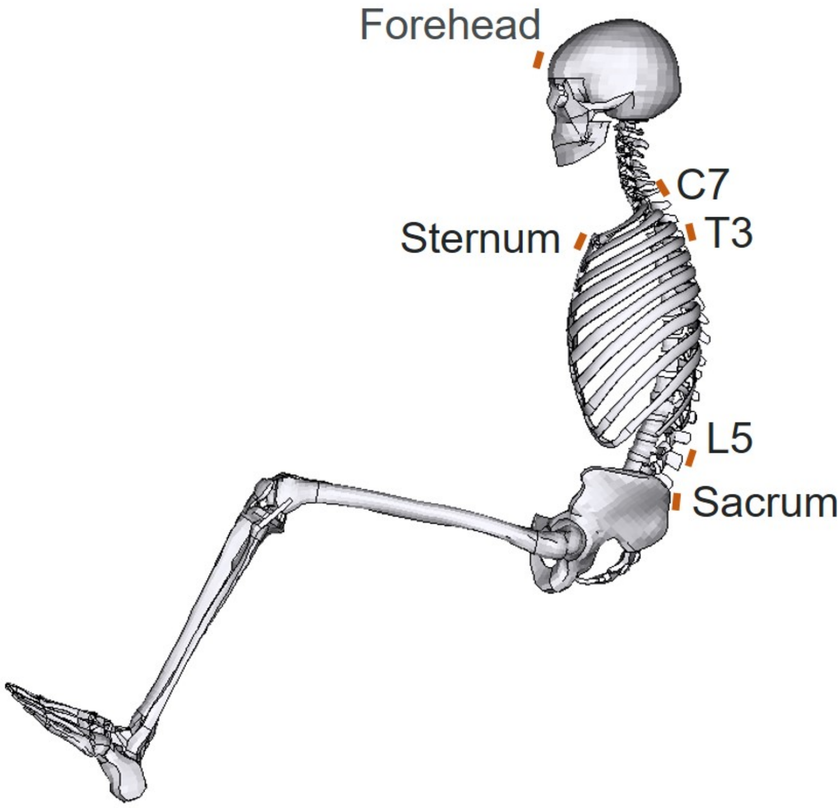

A study of sitting posture and belt position in a travelling car

How do passengers sit in a travelling car?

Master's thesis in Automotive and Biomedical Engineering

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Gothenburg, Sweden 2019

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Cover: Placement of Xsens sensors.

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Abstract

To improve the future design of restraint systems, it is important to know how passengers' sitting postures change over time and how the passengers interact with the restraint systems. This master thesis at Chalmers University of Technology, focuses on pelvis rotation, slouching and belt position while travelling in a front seat of a car on regular roads. The information was collected during normal drive in the passenger seat of a regular car, while the volunteers perform activities such as; resting, e-socializing and conversing.

Twenty volunteers, ten male and ten female, participated in the study. Volunteers were seated in the front row passenger seat, because this sitting posture is probably similar to how passengers will sit in future autonomous cars. The inertial motion measurement system MTw Awinda from Xsens, in total eight sensors, were used in the study. They were placed on the volunteer's sacrum, sternum, C7, T3, L5, forehead and car. The data from the sacrum sensor, that corresponds with pelvis rotation are mainly presented and discussed in this report. In addition, a surface pressure sensing array (Tekscan mat) was placed on the car seat cushion. The data from selected volunteers was analyzed with the TEMA to determine degree of slouching. Photo analysis was carried out to assess belt positions before and after the test. Additionally, the rotation of pelvis and sternum when changing seat back angle in intervals of 5° between 23° and 48° were also investigated.

The results show that pelvis rearward rotation increases by average 10° when riding in the car for about 45 minutes. Comparing the activities, the volunteers had similar average pelvis rotation. Slouching could be measured only for three volunteers out of 20 and it seemed to increase on average 3 cm during the ride. The belt position of initial and final sitting posture indicates that the diagonal belt moved less than the lap belt. To investigate the dynamic belt position, future video analysis is needed. Increasing seat back angle appeared to have a correlation with increasing sacrum and sternum pitch.

Keywords: sitting posture, belt position, pelvis rotation, sacrum pitch, slouching, Xsens and Tekscan mat.

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We are grateful for the help from the medical students Emil Cedergårdh och Jakob Bellman for teaching us about the skeleton.

Finally, we want to thank the FFI Assessment of passenger safety in future cars research group for all the input during the master thesis.

Annika Hansson and Emma Nilsson Lysén, Gothenburg, June 2019

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List of acronyms and abbreviations

ASIS	Anterior Superior Iliac Spine
BMI	Body Mass Index $[kg/m^2]$
cameras	video based motion measurements system, GoPro Hero 6
HBM	Human Body Model
sacrum pitch	rotation of sacrum around y-axis
Tekscan mat	surface pressure sensing array
Xsens	inertial motion measurements system
Xsens sensor	Xsens MTw Awinda sensor

List of definitions

belt position	Diagonal belt angle and lap belt angle in relation to the horizontal plane
e-socializing	passenger using hers/his phone
lap belt angle in front of iliac wing	The lap belt angle in relation to the vertical plane in front of iliac wing
seat position	Seat position such as seat back angle in relation to the vertical plane, seat cushion angle, seat cushion height, D-ring position, and seat position in x-axis
seating configuration	Front seat or rear seating position
sitting posture	Passenger posture in terms of position of whole body with focus on pelvis rotation and slouching
slouching	Movement of the pressure center produced by the ischial tuberosities fore-aft on the seat cushion

1

Introduction

This chapter is an introduction to the master thesis including; Section 1.1 *Background*, 1.2 *Objectives* and 1.3 *Limitations*.

1.1 Background

The seat belt is the passive safety system that saves the most amount of lives in car crashes. In the USA alone, 329 715 lives were saved between the years 1960-2012. Over half of the lives saved with car safety systems in 2012 were saved by seat belts [1]. However, for the seat belt system to work as intended, proper passenger sitting posture as well as belt routing is important. This is to ensure that the belt forces caused by energy from crashing or maneuvering are absorbed by the strongest parts of the body.

In terms of sitting posture, slouching influence the pelvis rearward rotation. Thereby, it has been suggested to increase the risk of the lap belt to slip off the pelvis, so called submarining [2]. This can result in an excessive force on the abdomen. The diagonal seat belt should be placed on the collarbone to prevent it from slipping off the shoulder and keeping the passenger close to the car seat.

There are several important terminologies in this study which explain passenger sitting posture and belt position;

- Passenger posture in terms of position of whole body with focus on pelvis rotation and slouching (sitting posture), see Figure 1.1.
- Movement of the pressure center produced by the ischial tuberosities fore-aft on the seat cushion (slouching), see Figure 1.2.
- Diagonal belt angle and lap belt angle in relation to the horizontal plane (belt position).
- Seat position such as seat back angle in relation to the vertical plane, seat cushion angle, seat cushion height, D-ring position, and seat position in x-axis (seat position), see Figure 1.2.

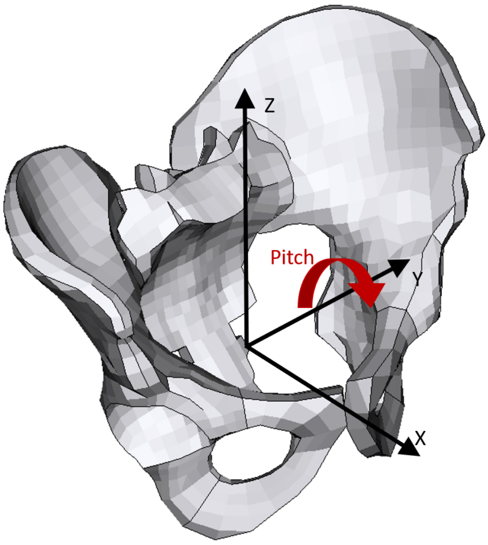

Figure 1.1: The coordinate system of pelvis, the rotation around the y-axis (pitch) and the movement along the x-axis are important in this report.

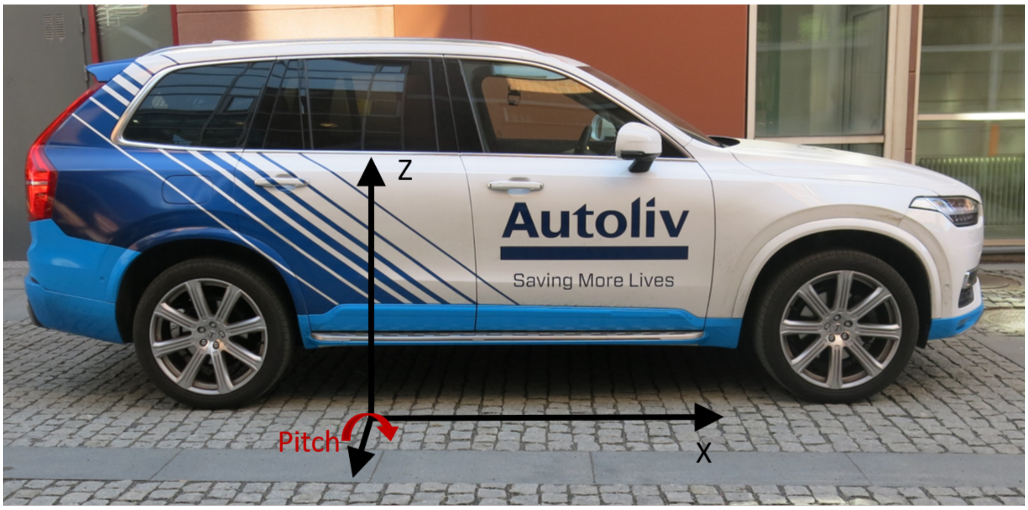

Figure 1.2: The coordinate system of a car, the rotation around the y-axis (pitch) and the movement along the x-axis are important in this report.

In a previous study, a method of measuring the sitting posture with a focus on pelvis rotation in a travelling car was developed [3]. The method used an inertial motion measurements system (Xsens), consisting of 17 sensors placed on the body. The study used a sensor positioned on sacrum to calculate the change of pelvis rotation. The result was verified with a measuring technique that used the landmarks Anterior Superior Iliac Spine (ASIS), Posterior Superior Iliac Spine (PSIS), relationships between bony landmarks and joints of the body to calculate the pelvis rotation [4]. The two methods measure the pelvis rotation in different ways, but the angle change was coinciding. However, Xsens need compensation for the movement of the car, which was not investigated in this study. Additionally, the Xsens sensors affected the natural behavior of the passengers, even though it was not to a larger extent.

Surface pressure sensing arrays, for example a Tekscan mat is able to measure the pressure distribution between the passenger and seat cushion. This system can be used in order to see how the passenger is slouching while travelling by car.

There is a lack of studies that reflect sitting posture variation while travelling by car. Additionally, there is a lack of knowledge of front seat passengers' sitting posture, even though this is probably similar to how passengers will sit in future autonomous cars.

1.2 Purpose

The main purpose is to determine pelvis rotation and slouching as a function of time of volunteers in the front passenger seat in a travelling car. The volunteer will perform the following activities; resting, e-socializing and conversing. The results will contribute to the positioning of Human Body Models (HBMs) in future simulations of pre-crashes and in-crashes in order to improve the future safety systems.

To fulfill the objectives, the following questions were to be answered:

- Which information of sitting posture and belt position is possible to extract during a volunteer study using an inertial motion measurement system and surface pressure sensing array?
- How is pelvis rotation, slouching and belt position varying as a function of travel time and between different activities for each volunteer?
- Is it possible to compare the sitting postures in this volunteer study to the previous developed statistical posture prediction models?

1.3 Limitations

Certain limitations were identified due to the time frame of the project and to make the results comparable. The limitations are stated below.

- 20 adults (10 male and 10 female) with a Body Mass Index [kg/m^2] (BMI) in the range of 18-30 will be studied.
- Tests will be performed in a forward facing front passenger seat of a passenger car.

- The test environment will affect the volunteer by for example having sensors taped on the body and cameras that are visual to the volunteer during the test.
- The volunteers were allowed to adjust the following seat adjustments; seat cushion in x-axis, seat back angle and D-ring position. The seat cushion height and seat cushion angle will be fixed.
- The landmarks of the bone's of the volunteers will only be identified by palpation, not with imaging techniques such as x-ray.

2

Theory

In this chapter, the background information of this thesis is presented. In Section 2.1 *Abdominal injuries caused by seat belt* submarining is explained. In Section 2.2 *Pelvis anatomy* the variation of pelvis is discussed. In Section 2.3 *Sitting posture* different models of sitting posture are explained. Section 2.4 *Activities performed while travelling by car* is about what passengers do while travelling. Section 2.5 *Sensors* presents the sensors that were used in the volunteer study.

2.1 Abdominal injuries caused by seat belts

Submarining is when the lap belt slides upward over the pelvis and load the abdomen in a frontal car crash [2]. One aspect that influences if submarining happens during a crash is sitting posture. The more rearward rotation of pelvis, the higher the risk that the lap belt slides upward during a crash. Other aspects that influence the risk of submarining is the lap belt orientation and if the belt has a pretensioner [2]. When submarining occurs, it can cause hollow abdominal organ injuries [5]. Therefore it is important to know the pelvis anatomy and how it is rotated when travelling in a car.

2.2 Pelvis anatomy

The pelvis anatomy is explained in this section to highlight how the individual anatomy of pelvis has an impact on the seat belt function in car crashes.

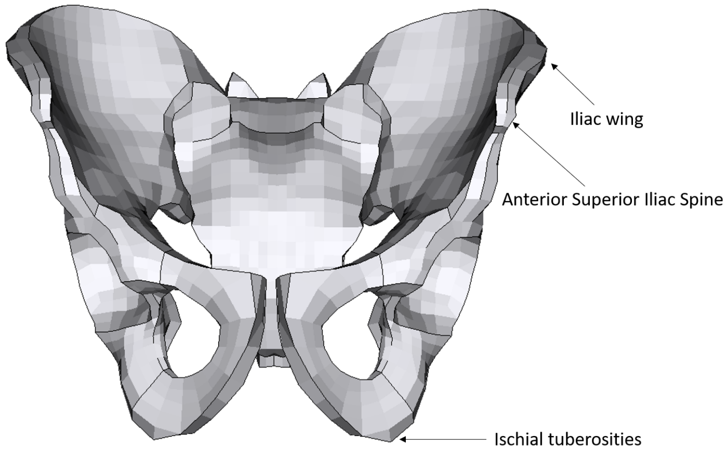

Figure 2.1: The anatomy of pelvis with the landmarks; iliac wing, anterior superior iliac spine, ASIS and ischial tuberosities.

2.2.1 Anatomical variation of pelvis

Pelvis is a complex part of the body, it mainly consists of the bones; right and left innominate bones and sacrum [6]. In Figure 2.1 three pelvis landmarks that are used when determining sitting posture in this study can be seen; iliac wing, Anterior Superior Iliac Spine (ASIS) and ischial tuberosities.

A 3D statistical model has been developed of the pelvis by evaluating CT scans of healthy adults [6]. The variation of pelvis depends on for example the shape of each bone and how they are aligned with each other, but also between males and females. The developed models show that there are differences, especially size and shape. It is not possible to generalize the pelvis shape only by external body measurements such as stature and weight.

2.2.2 Skeletal alignment of pelvis and spine

When positioning HBMs in crash test simulations, they need to be positioned in the seat and the seat belt needs to be fitted. The skeletal alignment of spine and pelvis are important factors that could influence the kinematics and the injury risk estimated in the simulated crashes. However, such knowledge is lacking since pelvis and spine alignment is difficult to measure on humans. To investigate this, a study was performed where volunteers were x-rayed sitting in a driver seat mock-up and in a standing posture [7]. Several parameters were used to analyze the skeletal alignment, for example angles between vertebrae and pelvis angle. When investigating the pelvis angle, there was a large variation of angles and no strong correlation to stature, BMI or age. The study concluded that further analysis of individual properties of pelvis is needed.

2.3 Sitting posture

In this Section sitting posture and how it changes over time is discussed and different models are shown.

2.3.1 Statistical models of sitting posture

There are statistical models of how sitting posture vary with for example age and body dimensions in driver and rear seats [8][9]. These posture prediction models can be used as guidelines to position HBMs when performing crash simulations. The rear seat model was developed by measuring landmarks, see Figure 2.2 of 89 volunteers in a mock-up that was a car seat in a laboratory [8]. The anthropometric dimensions used in the model can be seen in Table 2.1. The driver seat model was performed in a similar manner to the rear seat model. One exception was that the driver model took into consideration of the steering wheel center and the position of the pedal [9]. Today, there are no posture prediction models available for front seat passengers or how the sitting posture change over time.

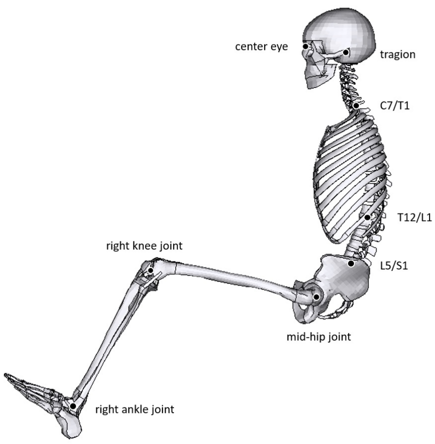

Figure 2.2: Predicted landmarks of the statistical models of sitting posture [8].

Variable	Unit
Age	Years
BMI	Body mass index $[kg/m^2]$
H30	Seat cushion height $[mm]$
S	Stature $[mm]$
SHS	Sitting height divided by stature $[-]$
A40	Seat back angle $[°]$.

Table 2.1: The input variables of the statistical model [8].

Apart from the statistical model just presented, there are also models that predict body angles depending on sitting posture. By collecting information about three different rear-seat sitting postures a posture model was developed [10]. The model predicts body angles for the scenarios; relaxing, standard and upright. The study was conducted in a laboratory mock-up with 20 volunteers that were measured with a stereo photography software. In order to force the volunteers to adjust the seat after their own preferences and not accept the previous settings, the initial position was set to an uncomfortable position. Thereafter the volunteer set the preferred settings for the scenarios. The study concluded that the relaxed position differed the most in terms of body angles compared to the others.

2.3.2 Adjusting sitting posture

While travelling in a car it has been shown that the driver adjusts the sitting posture [11]. Hermann (2010) showed that after approximately 30 minutes to 50 minutes, drivers need to readjust their sitting posture [11]. Another study conducted by Sammonds (2017) shows that drivers begin to adjust the sitting posture after 20-30 minutes, and thereafter the number of adjustments increase with travel time [12]. It can be assumed that the passengers also adjust their sitting posture in a similar way, but this has not been studied.

2.4 Activities performed while travelling by car

Different activities can be undertaken by passengers in cars. In future autonomous cars, the driver will be obsolete and everyone will become passengers. It has been shown that activities such as; passenger using hers/his phone (e-socializing), sleeping, looking out the window, resting, reading and working are activities people want to do in autonomous cars [13].

2.5 Sensors

In this section the function of the sensors Xsens and Tekscan mat that were used in this study are explained.

2.5.1 Xsens MTw Awinda sensors

Xsens is a wireless motion tracker system, Inertial-Magnetic Measurement Unit (IMMU), which consists of among others a 3D rate gyroscope and 3D accelerometer. The size of one Xsens sensor is 47 x 30 x 13 [mm]. The output from the Xsens sensors are transmitted to the Awinda Master wirelessly. Awinda Master is the link between the computer with Xsens software and the Xsens sensor. It makes sure that the data from every Xsens sensor is synchronized to 10 µs and has a range of up to 50m.

The output from a 3D gyroscope is angular velocity which can be integrated over time and thereby estimate the orientation. It can be delivered as euler representation, unit quaternions and as a rotation matrix. A drawback with integration is that the errors are added over time which could make the Xsens sensors drift. The 3D accelerometer outputs linear acceleration.

The Strap-Down Integration (SDI) algorithm is used due to the risk of decrease in output frequency which results in bad accuracy of the orientation. The SDI algorithm has an internal high sampling rate and thereby delivering a better accuracy at a lower output frequency. The data collection has a sampling frequency of 1000 Hz which then is filtered by a low pass filter with bandwidth 184 Hz. The SDI algorithm processes the data at the sampling frequency and calculates the orientation and velocity changes at a frequency in a range of 60 to 120 Hz depending on how many sensors are used.

The orientation output of the Xsens sensor have the earth-fixed coordinates as reference system. The sensor has a predefined coordinate system, seen in Figure 2.3. The euler angles are calculated in relation to the predefined coordinate system, where rotation around x-axis is roll, rotation around y-axis is pitch and finally, rotation around z-axis is yaw [14].

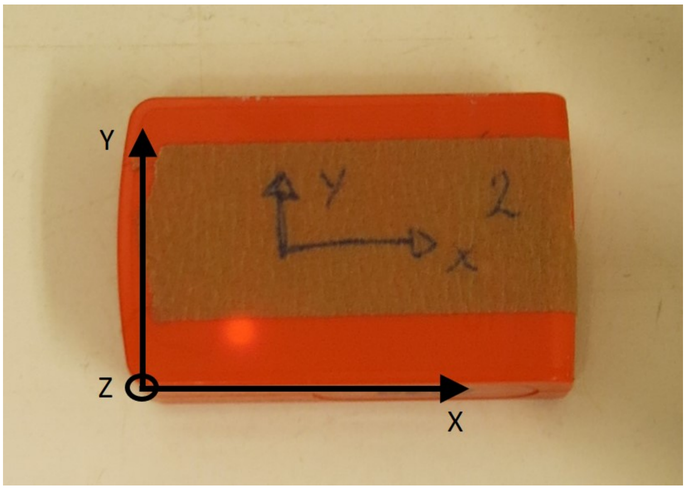

Figure 2.3: The coordinate system of Xsens sensor.

The implementation of Xsens sensors

The Xsens sensors can either be used independently or connected to each other in a Body Sensor Network [14]. For this project the Xsens sensors, software MVN Analyze and MT manager were available.

MVN Analyze connects 17 Xsens sensor to a Body Sensor Network, for this to work the sensors must be attached to predefined places on the body. This was used in the previously mentioned master thesis, where the sensor placed on sacrum was of interest [3]. To be able to use Xsens, some anthropometric dimensions are needed, see Table 2.2. These measurements are used to calculate the position of body parts since they are relatively few the 3D manikin is an estimation. If some additional Xsens sensor is needed on a non-predefined place on the body, this sensor has to be recorded in relation to one of the predefined sensors. So for example, it is not possible to record the Body Sensor Network and in addition have an extra sensor that records the car's movement independently.

MT Manager records the sensors independently and the output is orientation. This mean that there are not any restrictions on where to place the Xsens sensors. The drawback with MT Manager is that the position of the Xsens sensors cannot be estimated. Despite this MT Manager was chosen since there was larger flexibility for placing the sensors and the orientation output of pelvis and spine were of more interest. As well as being able to record the car's movement.

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Variable	Unit
Body height	$[mm]$
Foot length	$[mm]$
Shoulder height	$[mm]$
Shoulder width	$[mm]$
Arm span	$[mm]$
Hip height	$[mm]$
Hip width	$[mm]$
Knee width	$[mm]$
Ankle height	$[mm]$

Table 2.2: The variables needed to use Xsens.

2.5.2 Tekscan mat

A Tekscan mat, from Tekscan, model Medical Sensor 5330E [15], is an instrument that can be used in order to measure pressure distribution. The Tekscan mat used in this study is 471 x 471 [mm] and includes 1024 evenly distributed pressure sensors. They are divided into 32 rows and are located 1.47 cm in between each other [15]. The software installed on a computer that can be connected to the Tekscan mat is called I-Scan version 7.60. This system can be used for collecting pressure distribution, visualizing the output on a display in real time as well as a recorded movie. There is also a possibility to export the data into text files (ASCII) [16].

The sensors in the Tekscan mat sense pressure by using a technology called resistive-based. This means that when applying pressure on a sensor there is a resistance change in inverse proportion. The Tekscan mat can be equilibrated and calibrated and thereafter show the pressure distribution in desired units [16].

3

Methods of the volunteer study

In this chapter, the methods of the volunteer study is described. Section 3.1 *The volunteer study* has a more detailed description of how the volunteer study was carried out, explains the setup of measurement systems and the additional methods to collect the desired data. Section 3.2 *Data analysis* shows how the collected data was processed and analyzed.

3.1 The volunteer study

The volunteer study was conducted with 20 volunteers as front seat passengers in a Volvo XC90 car on regular roads in Gothenburg, further explained in Section 3.1.11. The collection of data of one volunteer consisted of the summarized steps below. In Appendix A.1 the complete checklist used during the study can be found. An ethical approval was obtained from the Ethical Review Board 2019-01758 (Etikprövningsmyndigheten).

1. Introduced the project and the volunteer signed a written consent.
2. The volunteer changed his/her clothes to tight and comfortable sportswear provided by the project group, see Figure 3.1.
3. Collected anthropometric measurements; such as length, weight and erect sitting height, see Section 3.1.1.
4. Equipped the volunteer with Xsens sensors with medical tape and a headband, see Section 3.1.2.
5. Attached a photo analysis marker and two small white balls on the volunteer, see marker 1 and 8 in Figure 3.8.
6. Took full body photos and photos of the attached Xsens sensors.
7. Asked the volunteer to enter the front passenger seat and choose a comfortable position by adjusting the seat back angle, seat position in x-axis and D-ring position, see Section 3.1.3.

8. Measured seat position, knee to dashboard, femur angle and lap belt angle in front of iliac wing, see Section 3.1.4.

9. Started the Tekscan mat and adjusted the sensitivity of the sensors, see Section 3.1.8.

10. Recorded standing and sitting position with Xsens, see Section 3.1.4.

11. Placed photo analysis markers and took photos of the volunteer's initial position in the seat, see Sections 3.1.5 and 3.1.6.

12. Aim the cameras towards the volunteer, see Section 3.1.7.

13. Synchronized Tekscan mat, Xsens and cameras, see Section 3.1.9 and started the tracking of the car, see Section 3.1.10.

14. One project member was driving and the other was managing the measurement systems during the ride, see Section 3.1.11.

15. When the data collection was finished, photos were taken of the volunteer's final position. Knee to dashboard, femur angle and lap belt angle in front of iliac wing were measured.

16. Recorded standing and sitting position with Xsens.

17. Recorded with Xsens and Tekscan mat while varying seat back angle, see Section 3.1.4.

18. Removed the Xsens sensor equipment before the volunteer filled out a questionnaire, see Section 3.1.1.

3.1.1 Volunteers

The volunteer study was done with 20 volunteers, 10 male and 10 female, that were recruited by the project team. Table 3.1 is a summary of the measurements taken of the volunteers that participated. In Appendix A.2.1 the complete table of all volunteers is shown.

	Male			Female		
	Average	Range	Swedish average (year 2003)	Average	Range	Swedish average (year 2003)
Age [years]	25	27 - 20		24	28 - 19	
Volunteer height [cm]	180	169 - 189	180	170	160 - 186	170
Sitting height [cm]	90	83 - 95		86	81 - 96	
Weight [kg]	78	66 - 89	78	66	57 - 74	64
BMI	24.2	21.5 - 27.2	24	22.8	18.6 - 25.5	22

Table 3.1: The recruited volunteers.

The volunteers borrowed comfortable sportswear, see Figure 3.1. At the beginning of the study, the volunteers were measured and weighed, see bullet list below and Appendix A.2. This was done to categorize the result.

- Volunteer height
- Volunteer height without shoes
- Erect sitting height
- Ear to ear
- Acromion to acromion
- Weight

At the end of the study, the volunteers were asked to fill out a questionnaire. It consisted of questions about their driving habits and how the measurement systems affected the volunteer's normal behavior. As well as collecting information about among others; biological sex and age. In Appendix A.3 the questionnaire and some answers can be found.

Figure 3.1: A volunteer in front, back, right and left view.

3.1.2 Xsens

The Xsens sensors were used in this project together with the software MT Manager, see Section 2.5.1. The sensors were placed with medical tape, see Figure 3.2, on the volunteer's sacrum, sternum, C7, T3 and L5. One sensor was placed with a headband on the forehead. To see photos of placement of all the Xsens sensors, see Appendix A.4. See Figure 3.3 of an illustration of where the sensors were placed.

Additionally, two sensors were placed in the car to record the orientation caused by driving. This was done in order to remove this orientation from the output of the other Xsens sensors. In order to make sure the angle change is due to the volunteer moving and not the car driving.

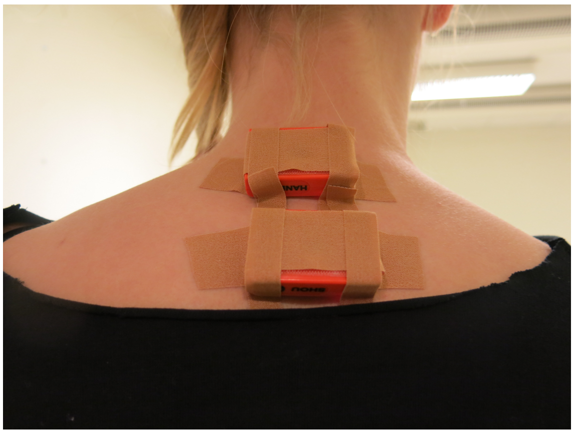

Figure 3.2: Example of the placement of sensors on C7 and T2.

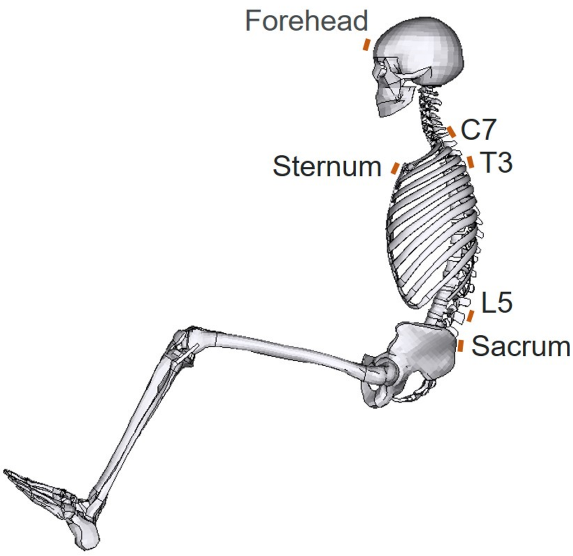

Figure 3.3: An illustration of the placements of the Xsens sensors on the volunteer.

All the sensors were placed with the y-axis upwards, x-axis directed to the volunteer's left and z-axis directed to the volunteer's front, explained in Figure 2.3, along with the z-axis of the car, explained in Figure 1.2. This placement was chosen in order to get the pitch movement of the car and body as the roll data output from the sensors. This was done since roll is the first angle calculated, so that roll has no impact from pitch and yaw.

3.1.3 Seating configuration and seat position

The volunteer study was carried out in the front passenger seat of a Volvo XC90, model 2015, and the following settings were applied:

- Seating configuration: Forward facing front passenger seat.
- Adjustable settings of seat position: seat back angle, D-ring position and seat position in x-axis, see Figure 3.4.
- Permanent settings of seat position; seat cushion angle, seat cushion height and back support. They were all set to the minimum setting.

The volunteers were only allowed to adjust seat position one time before the test and the settings were the same throughout the whole ride. In Figure 3.4 it is shown how the seat position was measured. The seat back angle was measured in the vertical plane with a spirit level placed on the back of the seat and a goniometer placed on the spirit level, as can be seen in the left figure. The reference angle of the seat back angle was 25° with the SAE J826 H-point manikin, which corresponds to a 23° seat back angle. In the middle figure, it is shown how the position of D-ring was measured. It was measured with a reference scale next to the D-ring, where zero was at the highest level. The right figure shows how the seat position in x-axis was measured with a reference scale. The zero point was when the seat was pushed to the very back. The seat cushion angle and height was set to the minimum settings.

Before the volunteer entered the car, the seat position in x-axis was pushed to the very front of the car (position 20 in Figure 3.4 right figure). The seat back was leaned forward as much as possible, see Figure 3.5. The D-ring position was set to zero (position 0 in Figure 3.4 middle figure). This was done in order to force the volunteer to adjust the settings to a preferred position, as explained in Section 2.3.1.

Figure 3.4: How seat back angle was measured (left figure). Reference scale next to the D-ring (middle figure). Reference scale on the seat rail (right figure).

Figure 3.5: The seat position before the volunteers adjusted the car seat.

3.1.4 Body measurements

Body measurements were collected inside the car when it was standing still, see list below and Figures 3.6 and 3.7.

- Knee to dashboard: the horizontal distance from knee to dashboard measured with a scale.
- Femur angle: the angle in relation to the horizontal plane on the top of the thigh measured with a goniometer placed on a flat board.
- The lap belt angle in front of iliac wing: The lap belt angle in relation to the vertical plane in front of iliac wing. A cube with dimensions 50 x 50 x 50 [mm] with a cut on the top to make the goniometer stable when measuring, see Figure 3.7, was placed on the lap belt in front of iliac wing after the volunteer had adjusted and tightened the lap belt to make sure it laid flat. The cube was pressed with 1kg on the lap belt to measure the angle.
- Xsens sensor pitch of standing and sitting, see Section 3.2.2.
- Xsens sensor pitch when varying seat back angle in intervals of 5° between 23° and 48°, see Section 3.2.6.

Figure 3.6: How knee to dashboard (left figure) and femur angle (right figure) were measured.

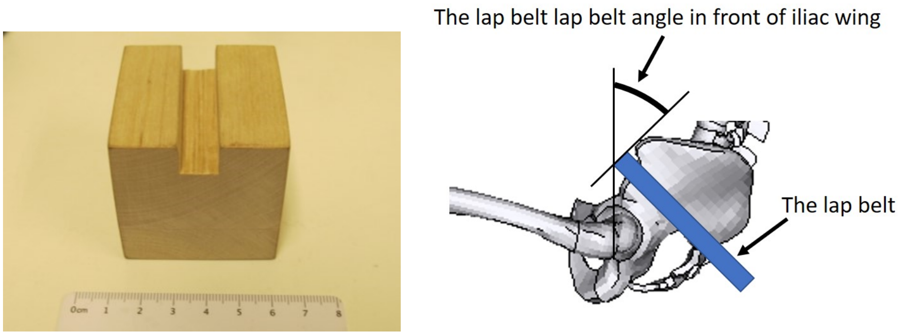

Figure 3.7: How lap belt angle in front of iliac wing was measured.

3.1.5 Photo markers

Photo markers were placed on the volunteer and on the seat belt. The markers were used together with photos, see Section 3.1.6, and cameras Section 3.1.7, to calculate diagonal and lap belt angles Section 3.2.3. Additionally, they could also be used for future video analysis of dynamic belt position.

The photo markers were placed according to the following description and can be seen in Figure 3.8.

- Marker 1: On the sternum sensor.
- Marker 2: On the diagonal belt, below marker 1.
- Marker 3: On the diagonal belt, 15 cm above marker 2 along the diagonal belt.
- Marker 4: On the diagonal belt, 15 cm below marker 2 along the diagonal belt.
- Marker 5: On the front of the lap belt, below marker 2.
- Marker 6: On the lap belt, just above seat cushion where the lap belt is flat.

Figure 3.8: Placement of photo analysis markers.

- Marker 7: On the lap belt, 8 cm above marker 6 along the lap belt.
- Marker 8: On the right and left acromion (small white balls instead of the photo analysis markers).

3.1.6 Photos

Photos were taken of each volunteer's initial and final sitting posture. In Appendix A.5 the placement of the camera is shown. Below, the photos are explained and examples are shown in Figure 3.9 and 3.10:

- Side view: camera placed 110 cm from the car and 110 cm above the ground.
- Side view with crossed arms: camera placed as in *side view*.
- Side view with focus on diagonal belt wrapping: camera placed 37 cm from the car and 110 cm above the ground.
- Front view: camera placed on dashboard 46 cm from position 20 on the seat rail in Figure 3.4, camera aimed towards the volunteer.

Figure 3.9: Example photo of the volunteer's sitting posture in side view.

Figure 3.10: Example photo of the volunteer's sitting posture in front view.

3.1.7 Cameras

To collect data for future video analysis of dynamic belt position and search for sources of error, two video based motion measurements system, GoPro Hero 6 (cameras) were mounted in the car with front and top view. In Figure 3.11 some example snapshots can be seen.

Figure 3.11: Example of the cameras' front and top views.

The cameras were placed on the ceiling and the windshield. This method made it easier to adjust the angles of the cameras to record how the volunteer is interacting with the belt. The front camera focused on the lap belt and the top camera focused on the diagonal belt. In Figure 3.12 it can be seen how the cameras were mounted in the car.

Figure 3.12: The placement of the cameras in the car.

3.1.8 Tekscan mat

Slouching is defined as the movement of the pressure center produced by the ischial tuberosities fore-aft on the seat cushion, see Figure 3.13. The Tekscan mat was attached to the seat cushion to measure how the volunteer moves during the ride. The Tekscan mat was placed on the seat between two rubber mats, see Figure 3.14. On top, there was a textile cover with comparable friction to the original car seat fabric to get a similar movement pattern.

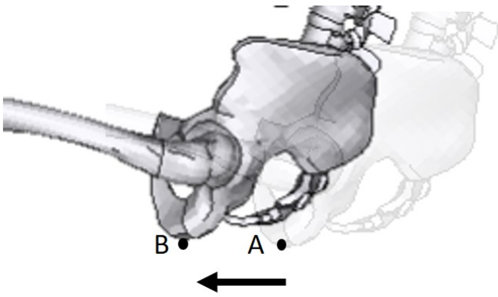

Figure 3.13: The ischial tuberosities moves forward from A to B, when the volunteer is slouching.

Figure 3.14: How Tekscan mat was fixed to the car seat and covered by fabric and rubber mats.

3.1.9 Synchronizing data

To make it possible to synchronize the measurements for slouching and pelvis rotation the Tekscan mat, Xsens and cameras needs a trigger. In this study, it was enough with one second accuracy since the movement of slouching and pelvis rotation are slow. To synchronize, one project member pressed the corner of the Tekscan mat which could be seen with the cameras at the same time as Xsens started recording. The volunteer was affected by the trigger because it was close to the volunteer's leg, so most of the volunteers needed to adjust their sitting posture during the synchronization.

3.1.10 Tracking the car's position

The orientation, position, acceleration, angular velocity and magnetic field data were collected by using the MATLAB Mobile App [17]. This was done in order to search for error sources and to be able to perform future analyzing of the data.

3.1.11 Activities for the volunteers and the route

The driven route consisted of three loops, each loop was approximately 7.3 km, see Figure 3.15. Approximately 1.3 km of the loop was driven on a two-lane expressway (Lundbyleden at Hisingen island, Gothenburg, Sweden), the rest of the road was in residential areas. During each loop the volunteers were asked to do one of the activities; resting, conversing and e-socializing. Different orders of the activities were chosen for each volunteer. When the volunteers were asked to rest, they were told to look out the window or close their eyes. When the volunteers were conversing it was with both the driver and the rear seat passenger. E-socializing meant that the volunteer used their phone freely.

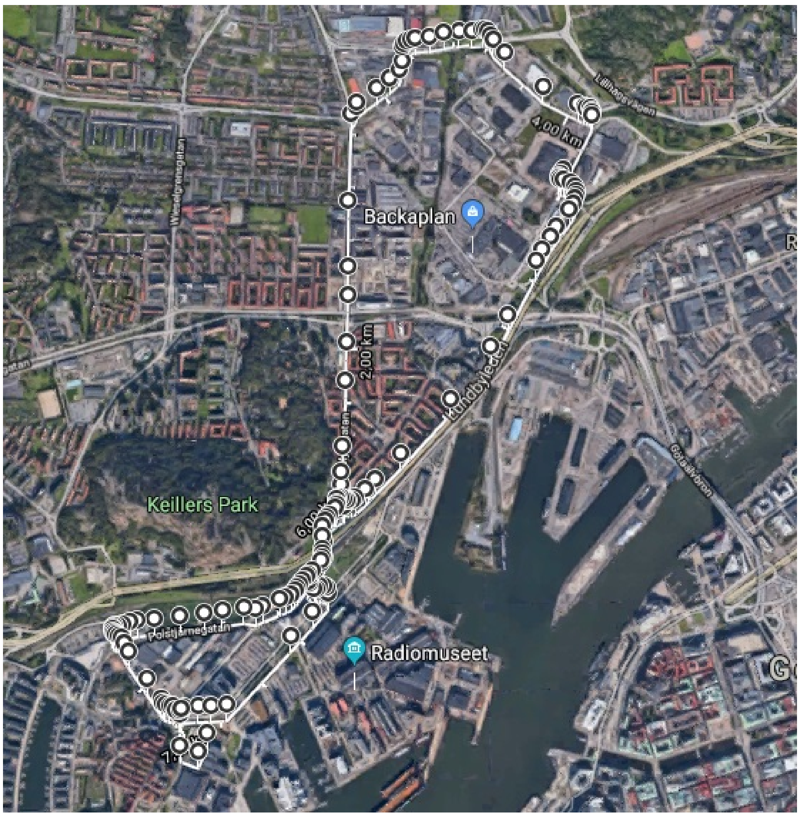

Figure 3.15: A map of the driven route.

3.2 Data analysis

This section describes the data analysis. Section 3.2.1 *Data processing* describe how the raw data was processed before it was analyzed. How the processed data was analyzed and presented is explained in the following five sections; 3.2.2 *Sacrum pitch of standing and sitting*, 3.2.3 *Belt position*, 3.2.4 *Dynamic sacrum pitch and lap belt angle in front of iliac wing*, 3.2.5 *Slouching* and 3.2.6 *Variation of seat back angle.*

3.2.1 Data processing

The raw data collected from Xsens and Tekscan mat was removed 1.5 minutes in the beginning and 1 minute in the end for each loop. This was done due to the method of synchronization which made the volunteer adjust the sitting posture. Thereby, the immediate change of sitting posture due to synchronization does not reflect the volunteers' natural movement.

Apart from removed beginning and end of each loop, two 2nd order Butterworth low pass filters were applied on the Xsens and Tekscan mat data. In the second filter the data was added in flipped order. The sampling frequency of the Xsens data was 100 Hz and the cutoff frequency was 0.1 Hz. For the Tekscan mat the sampling frequency was 4 Hz and the cutoff frequency was 0.015 Hz. The filtering was done in order to get rid of high-frequency noise and sharp peaks without distorting the signal. The noise was caused by vibration of the car. In Figure 3.16 it is shown how the unfiltered Xsens data and filtered data looks like.

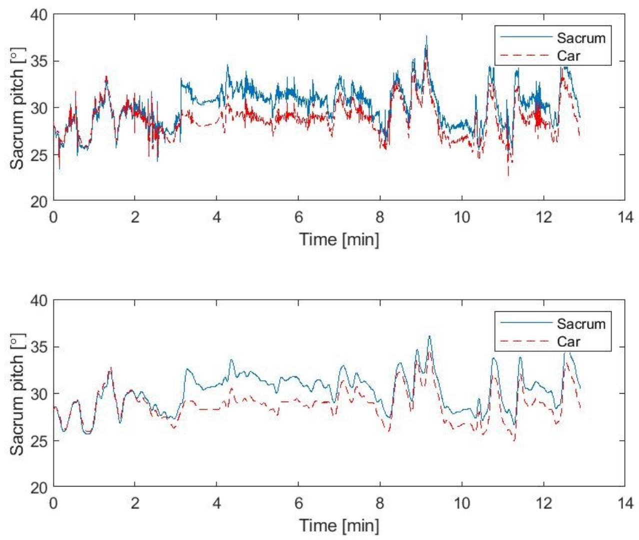

Figure 3.16: The top figure is an example of how unfiltered data from Xsens and the figure below is an example of the filtered data.

The angle from the Xsens sensors increases from the horizontal plane to towards the vertical plane. The angles for pelvis rotation that is presented in result increases from the vertical plane towards the horizontal plane. To convert the Xsens sensors angular output the equation 3.1 was used. See Figure 3.17 for an illustration of what the equation did, angle 1 is the orientation output from Xsens and angle 2 is pitch presented in results.

$$Pitch = ABS(Data\ from\ sensor - 90°) \tag{3.1}$$

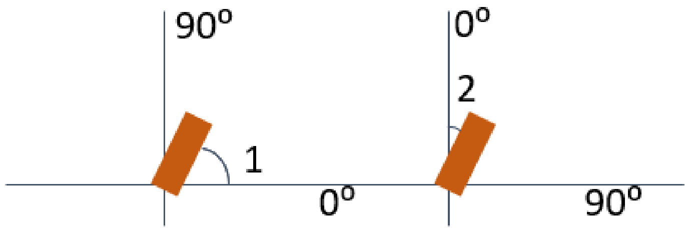

Figure 3.17: Angle 1 is the data from the sensor and angle 2 is pitch presented in results.

To calculate the pitch of the volunteer's body, the car pitch was subtracted from the other sensors, see Figure 3.18. In this study, the results from rotation of sacrum around y-axis (sacrum pitch) are presented, since that sensor corresponds to pelvis rotation. In Appendix B.1 the pitch of all sensors of volunteer 12 is shown.

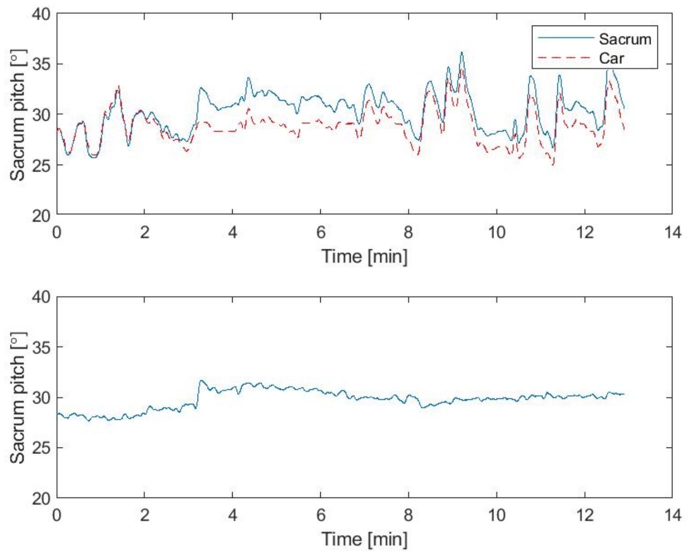

Figure 3.18: The top plot shows how sacrum and car pitch changes during a ride. The second plot shows sacrum pitch when car's pitch was removed.

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3.2.2 Sacrum pitch of standing and sitting

To be able to control if the Xsens sensors moved on the sacrum or drifted during the ride, the volunteer stood in a relaxed posture for 20 seconds along the x-axis of the car. Followed by, the volunteer sat down in the car seat for 20 seconds while data was recorded. This was done both before and after the test ride. An example of how the sacrum data from recording from standing and sitting can be seen in Figure 3.19. The pitch for standing and sitting was calculated by taking the average of each period. This also gives a recording on how the volunteer initial sitting posture.

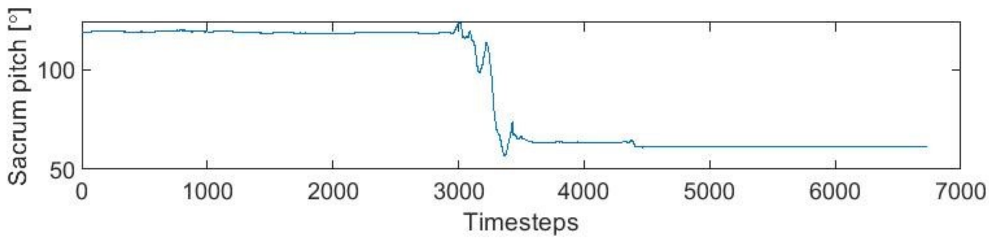

Figure 3.19: Example of the Xsens sensor data when recording Xsens sensor pitch of standing and sitting.

3.2.3 Belt position

The belt position was analyzed by investigating how much the belt angles; lap belt angle and diagonal belt angle, changed between before and after the ride. They were measured in projected angles, how they were measured are shown in Figure 3.20.

Figure 3.20: Example of how the diagonal belt angle and lap belt angle were determined in photos of the volunteers.

3.2.4 Sacrum pitch and lap belt angle in front of iliac wing

The focus of this study was the change of pelvis rotation during a car ride. Pelvis rotation was collected using the Xsens sensor placed on sacrum, which gave the sacrum pitch. Since pelvis can be considered a rigid body at loads induced during normal driving it was assumed that sacrum pitch change represented the pitch change of the whole pelvis. The variation over time of sacrum pitch was analyzed for each volunteer and for each loop, see Section 4.2.1. In Figure 3.21 the angle change for volunteer 1 during loop 2 can be seen as an example of how the pelvis rotation.

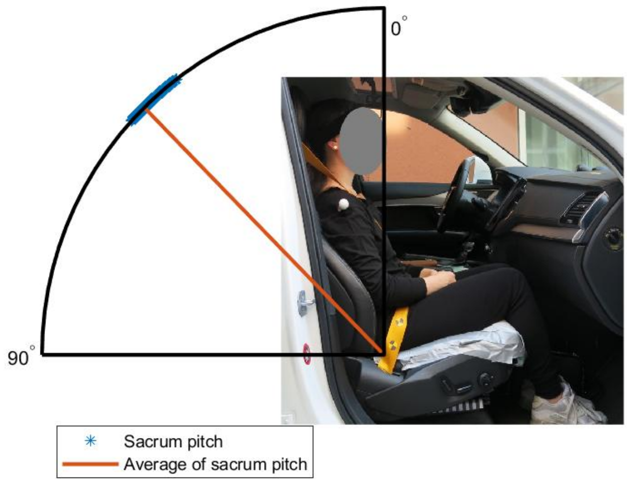

Figure 3.21: The sacrum pitch change for volunteer 16 during loop 3, the sacrum angle range was 10°.

The lap belt is interacting with the front of pelvis. Therefore, it is of interest to estimate what angle the lap belt has in relation to the vertical plane. This because of it inferences how the lap belt is interacting with the passenger's pelvis. In this report, this angle is referenced to as "lap belt angle in front of iliac wing". It was not possible to place an Xsens sensor on this part of the pelvis or belt segment. Instead, the angle was measured before and after the ride as explained in Section 3.1.4. It was assumed that the relation between sacrum pitch and lap belt angle in front of iliac wing is constant in a sitting posture. Therefore this relation could be added to the change of sacrum pitch. In Figure 3.22 an example of how lap belt angle in front of iliac wing changes over time is shown. The variation of lap belt angle in front of iliac wing was analyzed for each volunteer and for each loop, see Section 4.2.2.

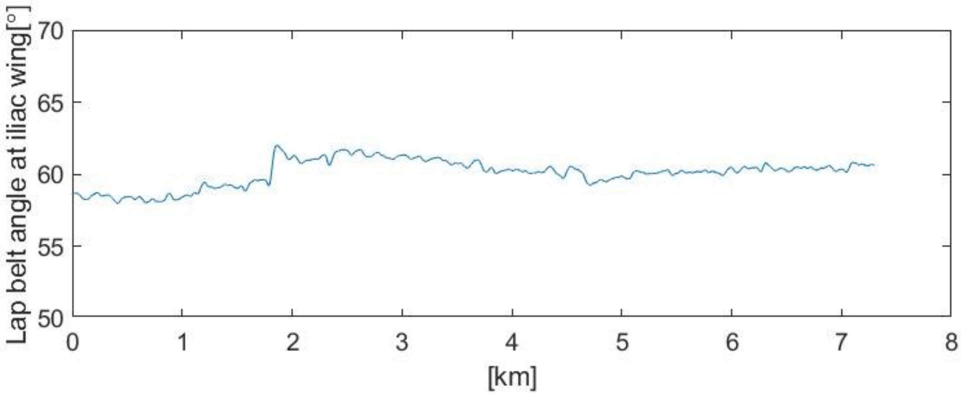

Figure 3.22: The assumed lap belt angle in front of iliac wing.

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3.2.5 Slouching

When sitting in a normal manner, it was possible to see the ischial tuberosities for volunteers 5, 10 and 12 on the Tekscan mat, but not for the other volunteers. The data from Tekscan mat of volunteer 5, 10 and 12 were saved as movies to be analyzed in TEMA. This is a software for motion tracking. The tracking points were placed on the left and right ischial tuberosities, see Figure 3.23. Figure 3.24 is an example of how the volunteer's ischial tuberosities moved on the seat cushion.

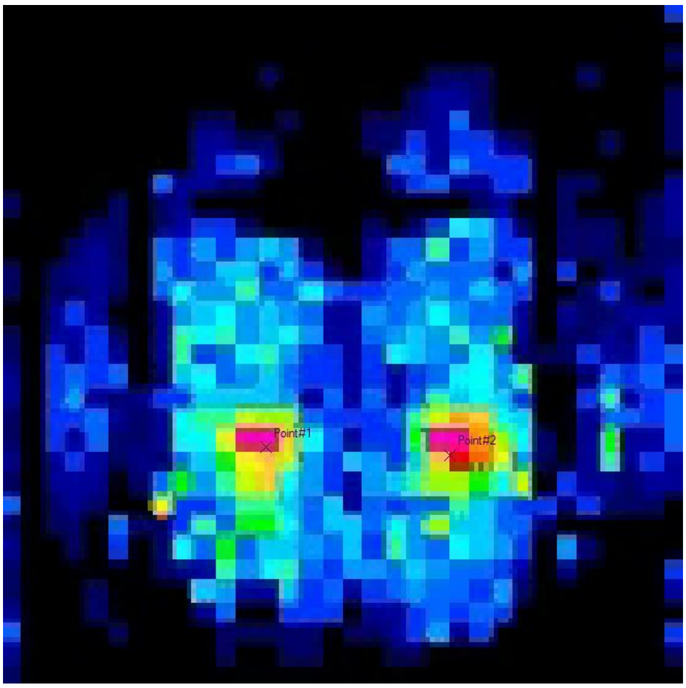

Figure 3.23: The tracking points of left and right ischial tuberosities in TEMA.

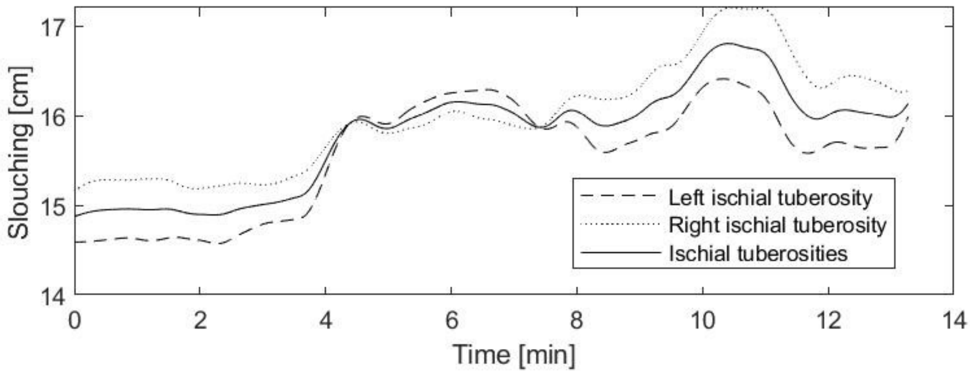

Figure 3.24: The movement of ischial tuberosities, analyzed in TEMA, loop 1 for Volunteer 12.

3.2.6 Variation of seat back angle

To investigate how much the seat back angle influences the angles of the body, a recording with Xsens was made after the ride. The seat back angle was firstly set to 23°, which represented the seat back angle when the H-point manikin is 25°. Then the volunteer was asked to sit comfortably and still for 15 seconds. After that, the same procedure for 28°, 33°, 38°, 43° and 48° was done. The pitch was calculated by taking the average pitch for each seat back angle. An example of the data is shown in Figure 3.25. The sacrum and sternum pitch were plotted in relation to each other and also in relation to the seat back angle in Section 4.3.2.

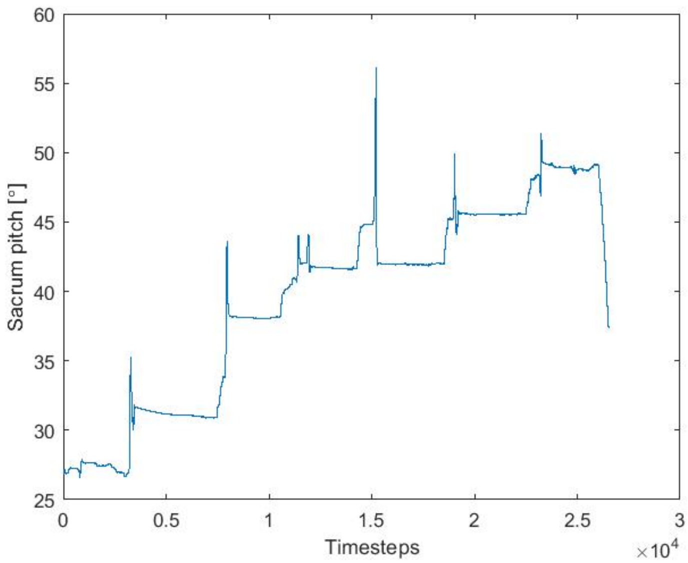

Figure 3.25: Example of the Xsens sensor data when changing the seat back angle.

4

Results

In this chapter the results are presented in the following three Sections; 4.1 *Static sitting posture and belt position*, 4.2 *Dynamic sitting posture* and 4.3 *Seats position's influence on sitting posture*. In the results, only the data from sacrum Xsens sensors is presented. The data from volunteer 17 has been removed which is explained in Section 5 *Discussion*.

4.1 Static sitting posture and belt position

This section presents the results from static sitting posture and belt position measurements divided into; 4.1.1 *Body measurements*, 4.1.2 *Sacrum pitch of standing to sitting* and 4.1.3 *Belt position*.

4.1.1 Body measurements

In Table 4.1 the body measurements collected before and after the ride for each volunteer is presented. The method of collecting this data is found in Section 3.1.4. The average distance knee to dashboard before/after is 12/10 cm, for male it is 11/10 cm and for female it is 13/11 cm. These average values imply that the distance between knee and dashboard decrease when measuring after the ride. The average femur angle before/after ride is 11°/14°, for male it is 11°/14° and for female it is 10°/14°. Overall the average femur angle increase over time. The average lap belt angle in front of iliac wing before/after ride is 68°/66°, for it is male 70°/66° and for female it is 66°/65°. The lap belt angle in front of iliac wing decreases when measuring after the ride.

Volunteer	Knee to dashboard [cm] (before/after)	Femur angle [°] (before/after)	Lap belt angle in front of iliac wing [°] (before/after)
Volunteer 1 (m)	11/8	17/14°	79/68°
Volunteer 2 (m)	13/13	4/7°	67/70°
Volunteer 3 (m)	11/12	0/13°	69/70°
Volunteer 4 (f)	15/12	7/13°	64/70°
Volunteer 5 (f)	10/11	26/10°	61/62°
Volunteer 6 (m)	13/12	8/11°	68/61°
Volunteer 7 (f)	12/9	9/14°	70/66°
Volunteer 8 (m)	17/14	25/22°	64/57°
Volunteer 9 (f)	12/14	23/23°	70/66°
Volunteer 10 (f)	13/13	5/28°	62/64°
Volunteer 11 (f)	12/11	0/5°	73/71°
Volunteer 12 (f)	13/11	3/10°	57/59°
Volunteer 13 (f)	15/13	16/12°	70/66°
Volunteer 14 (m)	9/7	16/18°	65/60°
Volunteer 15 (f)	9/9	10/14°	64/61°
Volunteer 16 (m)	13/10	17/18°	73/65°
Volunteer 18 (m)	8/7	6/6°	69/68°
Volunteer 19 (m)	5/4	10/14°	74/72°
Volunteer 20 (f)	14/5	4/10°	69/69°

Table 4.1: Body measurements collected from each volunteer, where (m) represents male and (f) represents female.

Figure 4.1 is a scatter plot that describes the relation between lap belt angle in front of iliac wing and volunteer height. The dots represent male volunteers and the diamonds represent female volunteers.

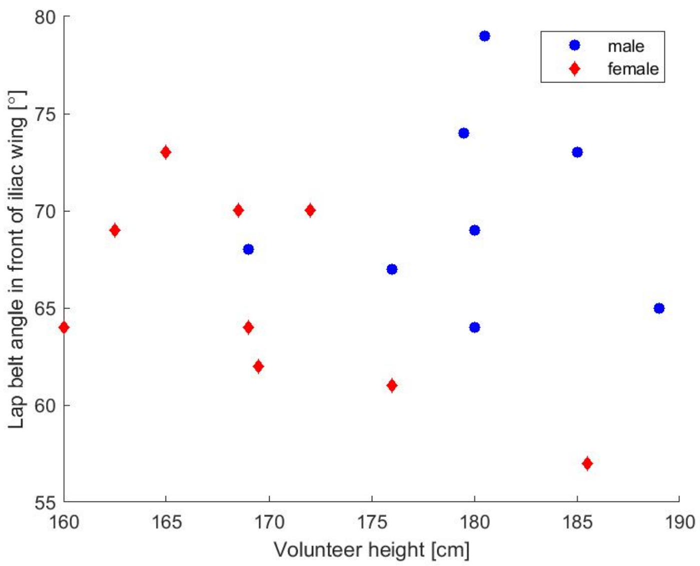

Figure 4.1: A scatter plot of volunteer height vs. lap belt angle in front of iliac wing.

4.1.2 Sacrum pitch of standing and sitting

The Xsens sensors recorded when the volunteer was standing and sitting, explained in Section 3.2.2. In Tables 4.2 and 4.3 the sacrum pitch recorded for this is presented. The difference between the recordings for before and after the ride is also presented. The average sacrum pitch difference of standing is 5°, for male it is 3° and for female it is 6°. The average difference of sitting is 2°, the same for male and female. It can be noticed that the average difference is lower for sitting than standing.

Volunteer	Before: Standing	After: Standing	Difference: Standing
Volunteer 1 (m)	23.0°	21.4°	1.7°
Volunteer 2 (m)	7.6°	13.0°	5.4°
Volunteer 3 (m)	4.5°	10.2°	5.8°
Volunteer 4 (f)	17.8°	19.1°	1.3°
Volunteer 5 (f)	8.3°	19.0°	10.6°
Volunteer 6 (m)	8.7°	13.4°	4.7°
Volunteer 7 (f)	1.2°	1.3°	0.1°
Volunteer 8 (m)	1.2°	4.9°	3.7°
Volunteer 9 (f)	17.4°	18.2°	0.8°
Volunteer 10 (f)	20.8°	26.2°	5.4°
Volunteer 11 (f)	44.4°	42.8°	1.6°
Volunteer 12 (f)	18.6°	28.8°	10.2°
Volunteer 13 (f)	7.6°	15.0°	7.4°
Volunteer 14 (m)	4.8°	0.7°	4.2°
Volunteer 15 (f)	13.8°	28.0°	14.2°
Volunteer 16 (m)	21.6°	20.4°	1.2°
Volunteer 18 (m)	17.1°	19.8°	2.7°
Volunteer 19 (m)	27.8°	26.3°	1.3°
Volunteer 20 (f)	10.4°	18.3°	7.9°

Table 4.2: Standing data from Xsens sacrum sensor for each volunteer, where (m) represents male and (f) represents female.

Volunteer	Before: Sitting	After: Sitting	Difference: Sitting
Volunteer 1 (m)	27.2°	29.6°	2.4°
Volunteer 2 (m)	27.0°	25.0°	2.0°
Volunteer 3 (m)	22.3°	18.6°	3.8°
Volunteer 4 (f)	32.2°	29.8°	2.4°
Volunteer 5 (f)	31.2°	31.3°	0.1°
Volunteer 6 (m)	27.5°	28.9°	1.4°
Volunteer 7 (f)	34.6°	30.1°	4.4°
Volunteer 8 (m)	30.8°	31.9°	1.1°
Volunteer 9 (f)	25.5°	22.6°	2.9°
Volunteer 10 (f)	15.2°	16.6°	1.5°
Volunteer 11 (f)	17.2°	16.1°	1.2°
Volunteer 12 (f)	26.7°	28.7°	2.0°
Volunteer 13 (f)	23.7°	23.6°	0.1°
Volunteer 14 (m)	27.2°	30.1°	2.9°
Volunteer 15 (f)	25.5°	26.1°	0.6°
Volunteer 16 (m)	29.8°	28.7°	1.2°
Volunteer 18 (m)	29.9°	28.8°	1.1°
Volunteer 19 (m)	24.5°	21.9°	2.6°
Volunteer 20 (f)	25.8°	29.9°	4.1°

Table 4.3: Sitting data from Xsens sacrum sensor for each volunteer, where (m) represents male and (f) represents female.

4.1.3 Belt position

The belt position was measured with the photos taken before and after the ride, explained in Section 3.2.3. Figures 4.2 and 4.3 are the volunteers with the largest respectively the smallest diagonal belt angles. In Table 4.4 it can be seen that for most volunteers the diagonal belt angle is similar or differ one degree when comparing before and after the ride. The average diagonal belt angle before and after the ride for both male and female is 56°. The lap belt angles had a larger variation than the diagonal belt, even though the average values before and after the ride is 73° for both male and female.

In Figure 4.4, the relation between diagonal belt angle and volunteer height is shown. The relation between lap belt angle and volunteer height is shown in Figure 4.5. The dots represent male volunteers and the diamonds represent female volunteers.

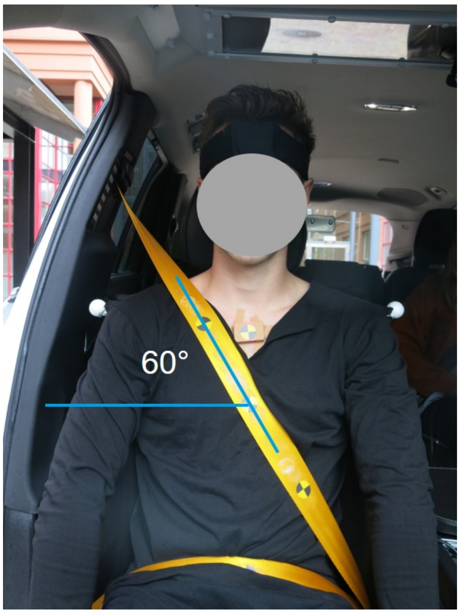

Figure 4.2: The volunteer with the largest diagonal belt angle was volunteer 18. The angle was 60°.

Figure 4.3: The volunteer with the smallest diagonal belt angle was volunteer 2. The angle was 53°.

Volunteer	Diagonal belt angle (Before/After)	Lap belt angle (Before/After)
Volunteer 1 (m)	54°/54°	74°/75°
Volunteer 2 (m)	53°/53°	70°/69°
Volunteer 3 (m)	55°/55°	67°/69°
Volunteer 4 (f)	58°/58°	74°/76°
Volunteer 5 (f)	58°/58°	68°/70°
Volunteer 6 (m)	56°/56°	74°/71°
Volunteer 7 (f)	57°/57°	76°/78°
Volunteer 8 (m)	58°/57°	74°/68°
Volunteer 9 (f)	56°/56°	73°/73°
Volunteer 10 (f)	57°/57°	70°/73°
Volunteer 11 (f)	55°/55°	74°/74°
Volunteer 12 (f)	56°/58°	79°/73°
Volunteer 13 (f)	53°/52°	67°/67°
Volunteer 14 (m)	56°/56°	74°/72°
Volunteer 15 (f)	57°/56°	72°/73°
Volunteer 16 (m)	55°/55°	70°/75°
Volunteer 18 (m)	60°/61°	84°/81°
Volunteer 19 (m)	59°/59°	74°/75°
Volunteer 20 (f)	56°/57°	71°/75°

Table 4.4: Seat belt angles before and after the ride, where (m) represents male and (f) represents female.

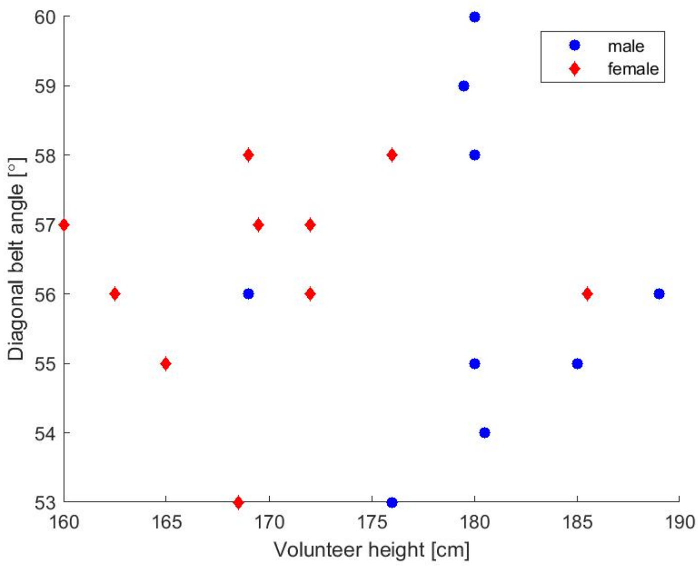

Figure 4.4: A scatter plot of volunteer height vs. diagonal belt angle.

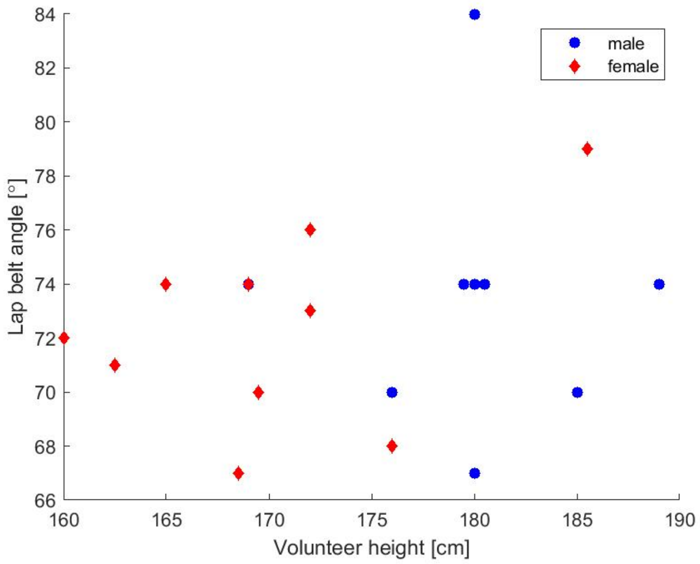

Figure 4.5: A scatter plot of volunteer height vs. lap belt angle.

4.2 Dynamic sitting posture

This section presents the results of dynamic sitting posture divided into; 4.2.1 *Sacrum pitch*, 4.2.2 *The lap belt angle in front of iliac wing* and 4.2.3 *Slouching*.

4.2.1 Sacrum pitch

The data from sacrum pitch corresponds to pelvis rotation, as explained in Section 3.2.4. Figures 4.6 and 4.7 show the volunteers with the largest respectively the smallest range of sacrum pitch. In Table 4.5 the average values and average range of sacrum pitch are shown, where range is the maximum sacrum pitch subtracted with minimum sacrum pitch for each volunteer. In Tables 4.6 and 4.7 the results are divided into male and female. The values are calculated for each activity and each loop separately, as well as for total test time. It can be seen in almost all cases that the average values and average range increase over time. The largest average value is found in loop 3 for all cases. Additionally, one average ride (loop 1-3) took 36 minutes, maximum 45 minutes and minimum 31 minutes. The complete table with average values, range of sacrum pitch and travel time for each volunteer can be found in Appendix B.3.

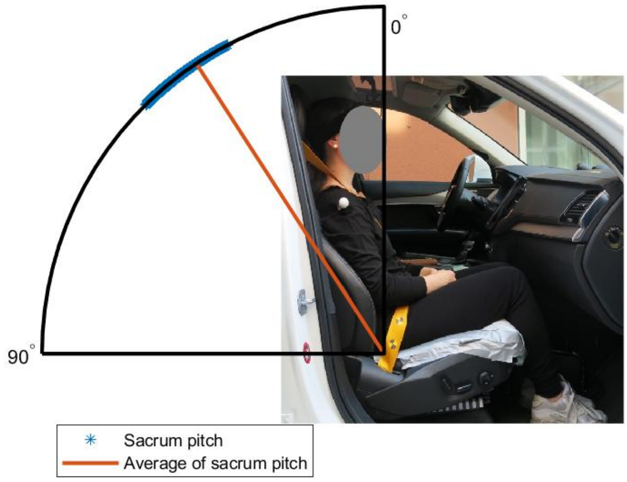

Figure 4.6: The volunteer that moved the most was volunteer 1 during loop 2. The change was 17°.

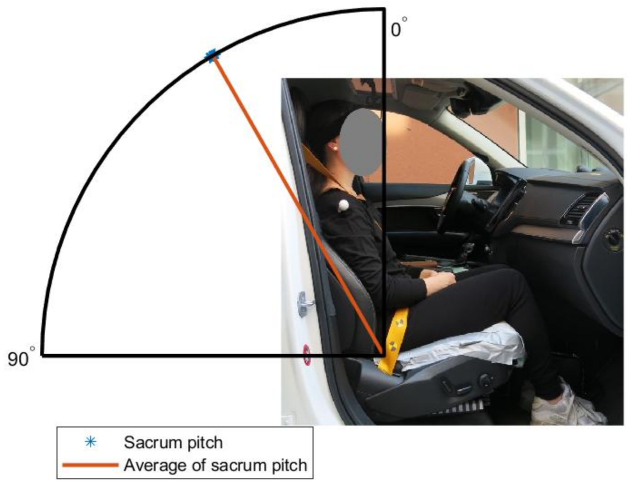

Figure 4.7: The volunteer that moved the least was volunteer 9 during loop 2. The change was 1°.

Period	Average	Average: Max	Average: Min	Average: Range	Travel time
Resting	32.4°	34.2°	30.4°	3.8°	12.7 min
E-socializing	31.5°	34.0°	28.9°	5.1°	11.7 min
Conversing	30.6°	32.1°	28.7°	3.4°	12.3 min
Loop 1	29.3°	30.7°	27.4°	3.3°	12.4 min
Loop 2	31.2°	33.3°	28.9°	4.4°	11.7 min
Loop 3	34.0°	36.3°	31.8°	4.5°	12.0 min
Total test time	31.5°	36.8°	26.9°	9.9°	35.9 min

Table 4.5: Average absolute angle of sacrum pitch for all volunteers.

Period	Average	Average: Max	Average: Min	Average: Range	Travel time
Resting	33.4°	35.8°	31.0°	4.8°	12.7 min
E-socializing	33.2°	36.3°	29.9°	6.4°	12.5 min
Conversing	30.7°	32.5°	28.6°	3.9°	12.3 min
Loop 1	29.9°	31.6°	27.8°	3.8°	12.8 min
Loop 2	31.9°	34.9°	28.7°	6.2°	12.0 min
Loop 3	35.5°	38.0°	33.0°	5.0°	12.9 min
Total test time	32.4°	38.8°	27.3°	11.5°	37.7 min

Table 4.6: Average absolute angle of sacrum pitch for male volunteers.

Period	Average	Average: Max	Average: Min	Average: Range	Travel time
Resting	31.4°	32.7°	29.9°	2.8°	11.2 min
E-socializing	29.7°	31.7°	27.9°	3.8°	10.9 min
Conversing	30.5°	31.8°	28.9°	2.9°	12.4 min
Loop 1	28.6°	29.8°	27.0°	2.8°	12.0 min
Loop 2	30.5°	31.7°	29.2°	2.5°	11.4 min
Loop 3	32.5°	34.6°	30.5°	4.1°	11.0 min
Total test time	30.5°	34.8°	26.5°	8.3°	34.4 min

Table 4.7: Average absolute angle of sacrum pitch for female volunteers.

In Figures 4.8, 4.9 and 4.10 the change of sacrum pitch is shown for each loop. The average value of the first second (100 time steps) from loop 1 was chosen as the initial sacrum pitch. Therefore, the graphs represent the sacrum pitch change from the beginning of loop 1. The x-axis of the figures was set to distance in kilometers since every route took a different amount of time due to traffic. It can be noticed that after each loop the variation between the volunteers is larger. Some volunteers have a greater variation, either one quick movement that increases the sacrum pitch or slowly increasing it. In Appendix B.3 the graphs are divided into male and female for each loop, as well as activity.

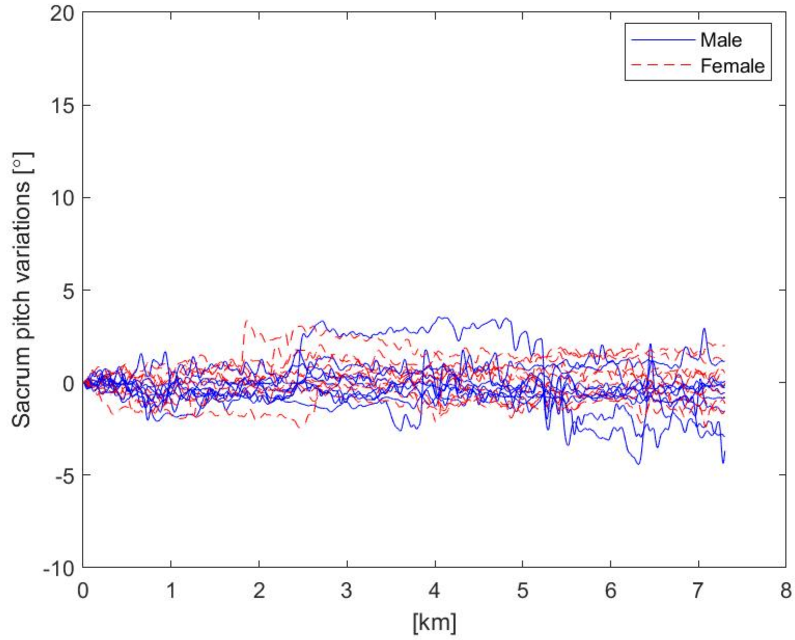

Figure 4.8: The sacrum pitch variation for loop 1.

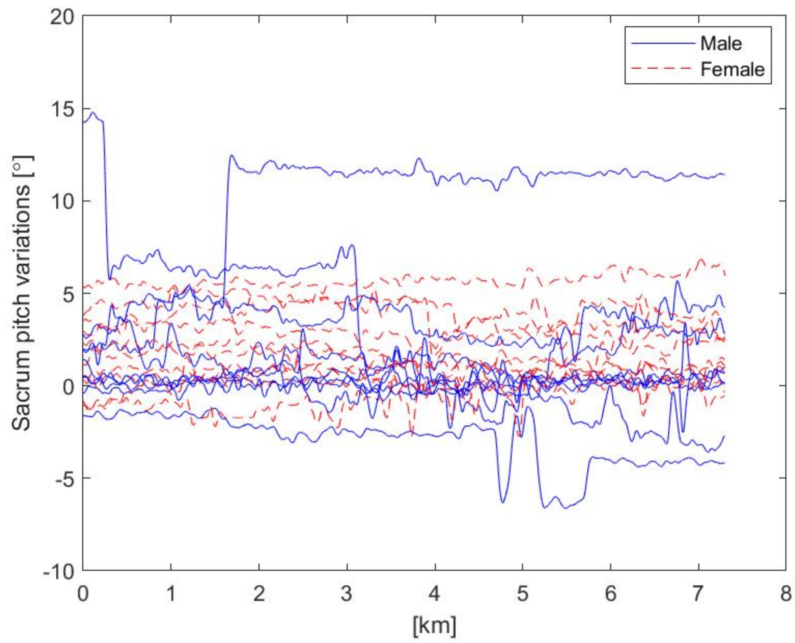

Figure 4.9: The sacrum pitch variation for loop 2.

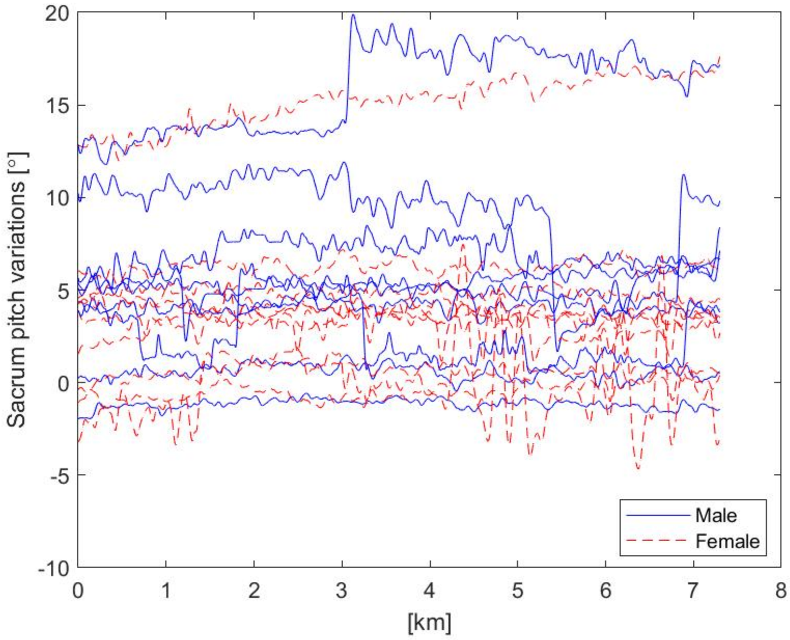

Figure 4.10: The sacrum pitch variation for loop 3.

In Figure 4.11 the relation between the total change of sacrum for each volunteer (total sacrum range) and volunteer height can be seen. The dots represent male volunteers and the diamonds represent female volunteers. It can be noticed that most volunteers have a total range between 5° and 10°.

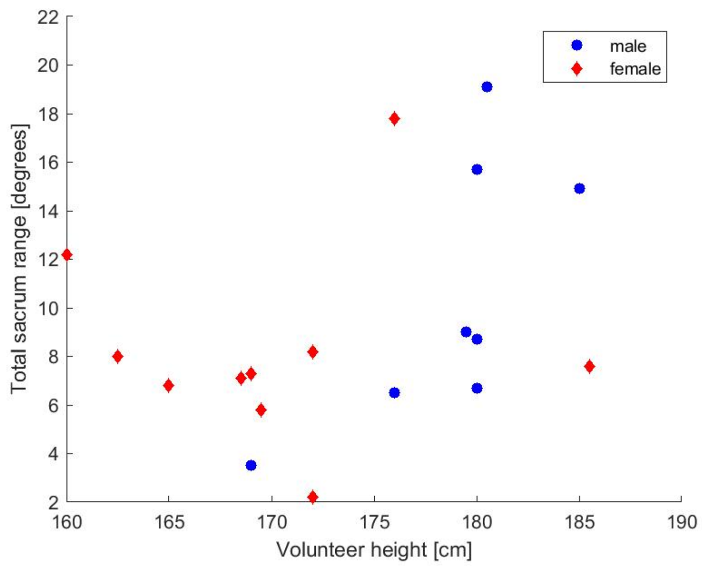

Figure 4.11: A scatter plot of volunteer height vs. total sacrum range.

4.2.2 The lap belt angle in front of iliac wing

The graphs of lap belt angle in front of iliac wing are presented in Figures 4.12, 4.13 and 4.14. These are suggested absolute angles as explained in Section 3.2.4. In the graphs it can be seen how the lap belt angle in front of iliac wing changes for each volunteer. Most of the volunteers have a lap belt angle in front of iliac wing around 60° to 80°. Since these graphs are derived from Section 4.2.1, the change of the angle is the same as the change of sacrum pitch. In Appendix B.4 the graphs divided into male and female and Table B.3 where lap belt angle in front of iliac wing for each volunteer are listed can be found. There are also graphs divided in to resting, E-socializing and conversing.

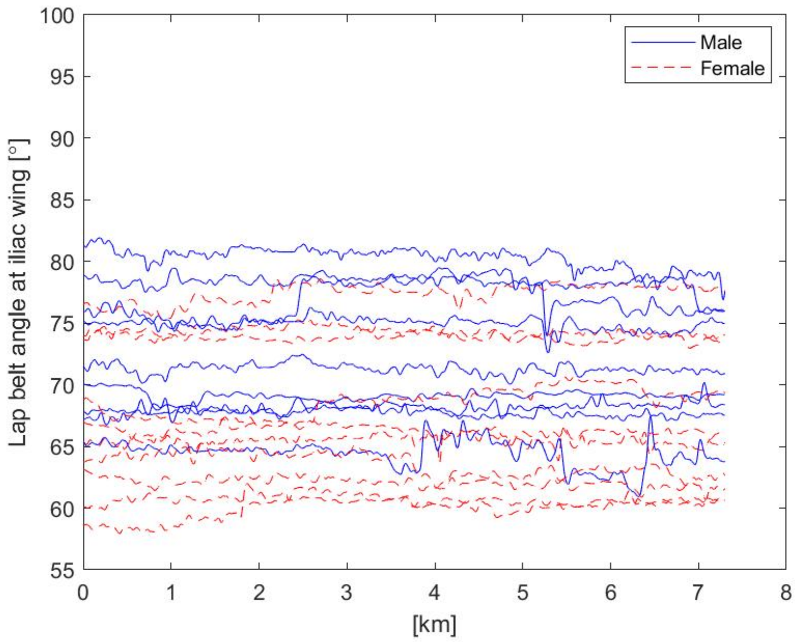

Figure 4.12: The lap belt angle in front of iliac wing for loop 1.

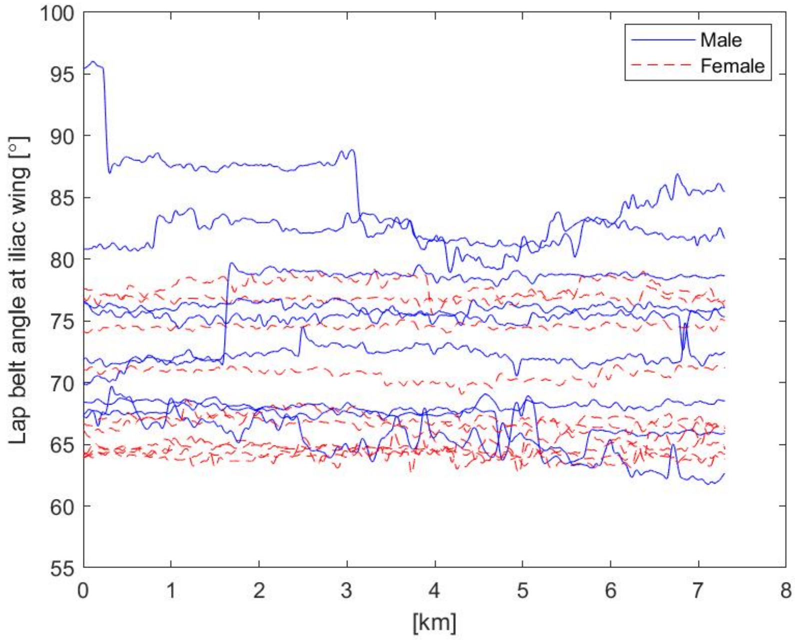

Figure 4.13: The lap belt angle in front of iliac wing for loop 2.

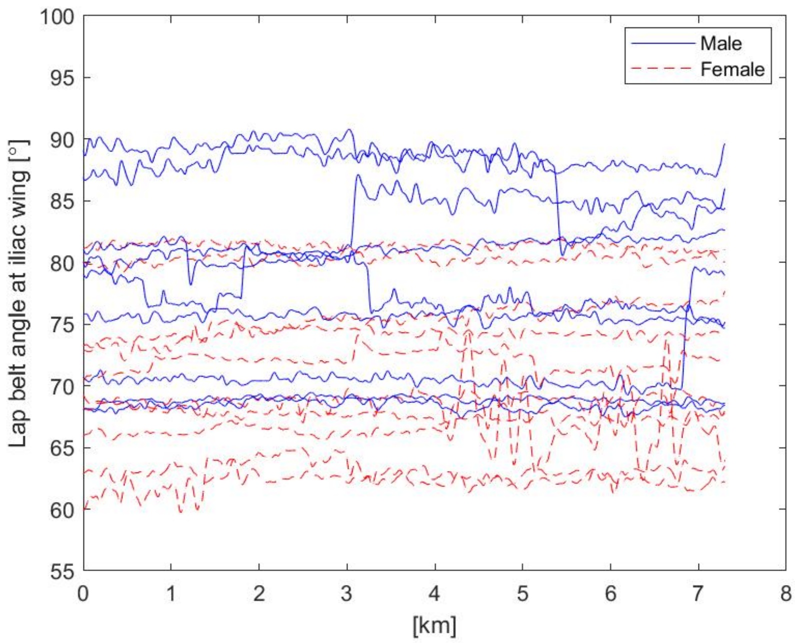

Figure 4.14: The lap belt angle in front of iliac wing for loop 3.

4.2.3 Slouching

Slouching is the movement of ischial tuberosities on the seat cushion, as explained in Section 3.2.5. In Table 4.8, the average, minimum and maximum position as well as the total movement of the ischial tuberosities are presented for three volunteers. Figure 4.15, 4.16 and 4.17 show how the volunteers move their ischial tuberosities on the seat cushion during the three loops. It can be noticed that the ischial tuberosities have moved further on the seat cushion for each loop. The average movement of all volunteers is 3 cm forward on the seat cushion.

Volunteer	Average [cm] Left/Right	Min [cm] Left/Right	Max [cm] Left/Right	Total movement [cm] Left/Right (both)
Volunteer 5 (f)				
Loop 1	17.9/17.7	17.5/17.6	18.1/17.6	0.6/0.4 (0.5)
Loop 2	18.6/18.0	18.4/17.0	19.0/18.4	0.7/1.4 (1.1)
Loop 3	19.9/-	19.0/-	20.4/-	1.4/ - (1.4)
Total	18.8/17.8	17.5/17.0	20.4/18.4	2.9/1.4 (2.2)
Volunteer 10 (f)				
Loop 1	14.9/15.3	14.1/14.8	15.1/15.9	1.1/1.1 (1.1)
Loop 2	16.7/16.3	16.6/15.6	17.3/16.8	0.7/1.1 (0.9)
Loop 3	16.4/17.1	15.9/16.3	17.2/18.8	1.3/2.5 (1.9)
Total	16.0/16.2	14.1/14.8	17.3/18.8	3.3/4.0 (3.7)
Volunteer 12 (f)				
Loop 1	15.6/16	14.6/15.2	16.4/17.2	1.8/2.0 (1.9)
Loop 2	14.6/16.4	13.6/15.8	16.0/17.1	2.4/1.3 (1.9)
Loop 3	17.0/17.4	16.6/16.5	17.9/18.3	1.3/1.8 (1.6)
Total	15.6/16.5	13.6.4/16.2	17.9/18.3	4.3/3.1 (3.7)

Table 4.8: Position of ischial tuberosities on the seat cushion, where (f) represents female.

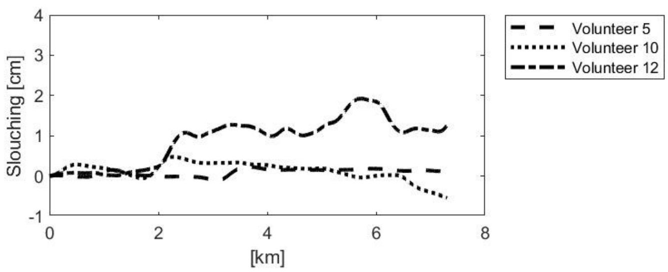

Figure 4.15: Slouching on the seat cushion for loop 1.

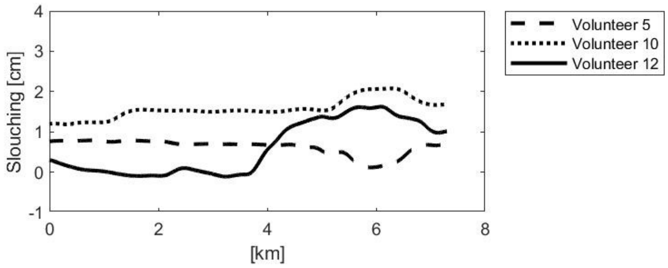

Figure 4.16: Slouching on the seat cushion for loop 2.

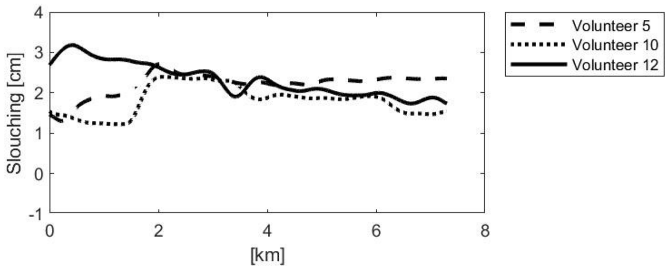

Figure 4.17: Slouching on the seat cushion for loop 3.

4.3 Seat position's influence on sitting posture

This section presents the results how sitting posture is influenced by seat position, divided into; 4.3.1 *Seat position* and 4.3.2 *Variation of seat back angle*

4.3.1 The volunteers' seat position

In Table 4.9 the seat position in terms of seat back angle, position of the seat in x-axis and the D-ring position chosen by each volunteer is shown. The explanation of how the position was measured can be found in Section 3.1.3. The average seat back angle of the volunteers is 23°, for male 22° and for female 23°. The average setting of seat cushion in x-axis is 13 cm for male and female, where the setting 0 cm is the seat pushed to the back and 20 cm is pushed to the very front. The average D-ring position is 2 cm, for male 1 cm and for female 3 cm, where the setting 0 cm is when the D-ring is in the highest position and 8 cm is the lowest position. The most common position for both male and female was 0 cm.

In Figure 4.18 the relation between seat back angle and volunteer height can be seen. It is observed that most volunteers set the seat back angle between 22° and 24°. In Figure 4.19 the relation between seat cushion in x-axis and volunteer height is shown. It appears that the seat cushion in x-axis is mostly set between 8 cm and 18 cm. The dots represent male volunteers and the diamonds represent female volunteers in both figures.

Volunteer	Seat back angle [°]	Seat in x-axis [cm]	D-ring position [cm]
Volunteer 1 (m)	26°	13.5	0
Volunteer 2 (m)	20°	11	2
Volunteer 3 (m)	21°	8	0
Volunteer 4 (f)	23°	10.5	0
Volunteer 5 (f)	24°	12	0
Volunteer 6 (m)	24°	15.5	0
Volunteer 7 (f)	23°	11	5.5
Volunteer 8 (m)	19°	7	0
Volunteer 9 (f)	22°	11.5	0
Volunteer 10 (f)	19°	10.5	0
Volunteer 11 (f)	24°	14	0
Volunteer 12 (f)	24°	7.5	4
Volunteer 13 (f)	22°	10.5	7
Volunteer 14 (m)	20°	14.5	4
Volunteer 15 (f)	23°	20	7
Volunteer 16 (m)	22°	12	0
Volunteer 18 (m)	25°	17	0
Volunteer 19 (m)	22°	19	0
Volunteer 20 (f)	24°	17	7

Table 4.9: The seat position chosen by each volunteer, where (m) represents male and (f) represents female.

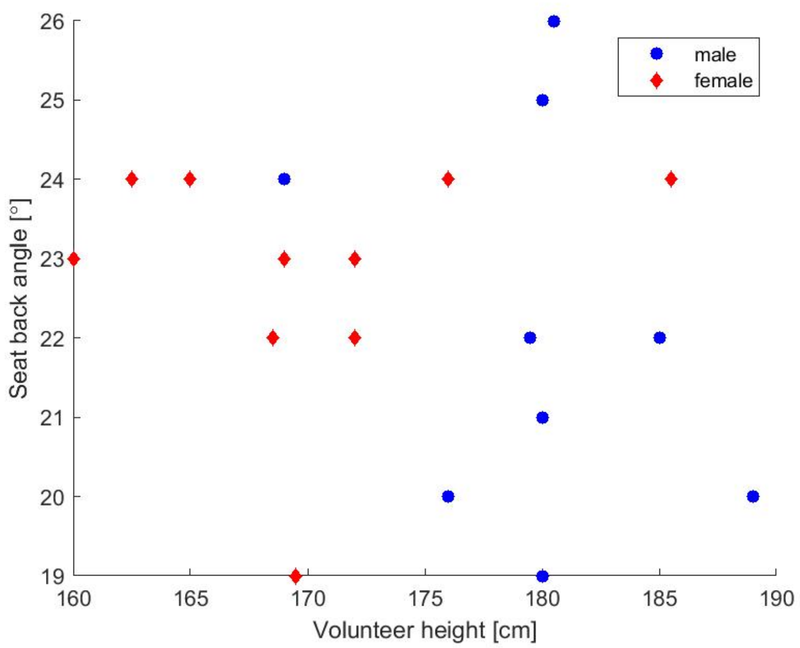

Figure 4.18: Scatter plot of volunteer height vs. seat back angle.

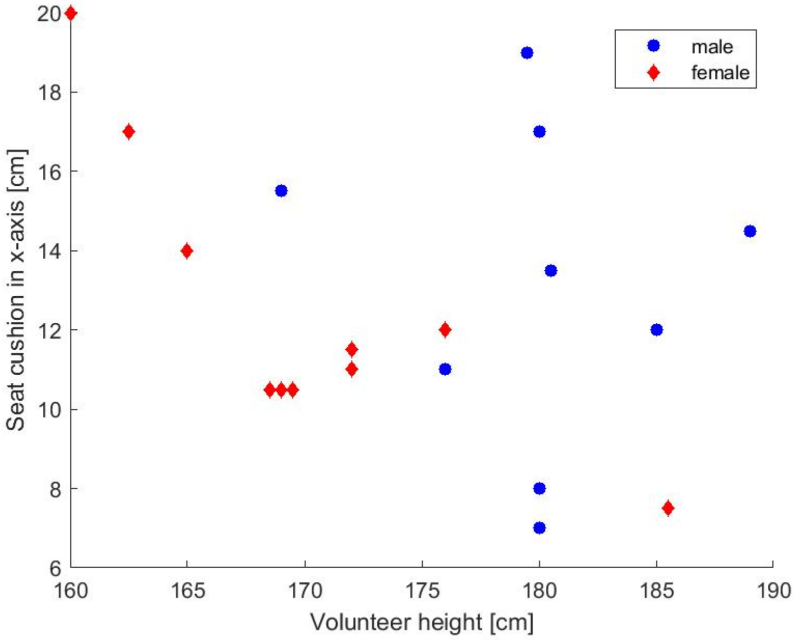

Figure 4.19: Scatter plot of volunteer height vs. seat cushion in x-axis.

4.3.2 Variation of seat back angle

The seat back angle was changed between 23° to 48° in 5° intervals, explained in Section 3.2.6. In Figure 4.20 the relationship between sacrum pitch and sternum pitch is presented. The left figure shows sacrum pitch and sternum pitch set to zero at a seat back angle of 23°. In the right figure, the absolute pitch values are shown. The black squares illustrate the seat back angle at 23° and thereafter the seat back angle increase to the right.

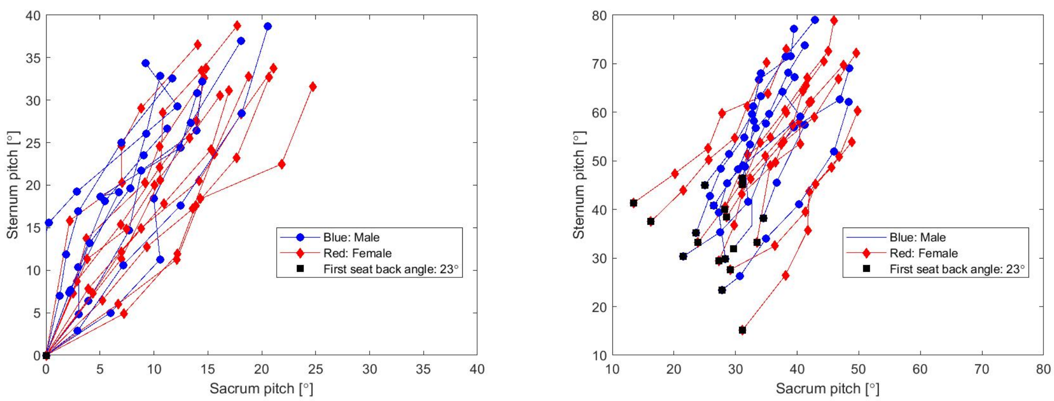

Figure 4.20: In the left figure sacrum angle vs. sternum angle is shown when the initial angles are set to zero. In the right figure sacrum angle vs. sternum angle is shown in absolute values.

In Figure 4.21 the relation between seat back angle and sacrum pitch as well as seat back angle and sternum pitch are presented. In both figures the pitch at seat back angle 23° is set to zero. It is noticed that for all volunteers both sacrum and sternum pitch increase with seat back angle. Additionally, sternum pitch increases faster than sacrum pitch.

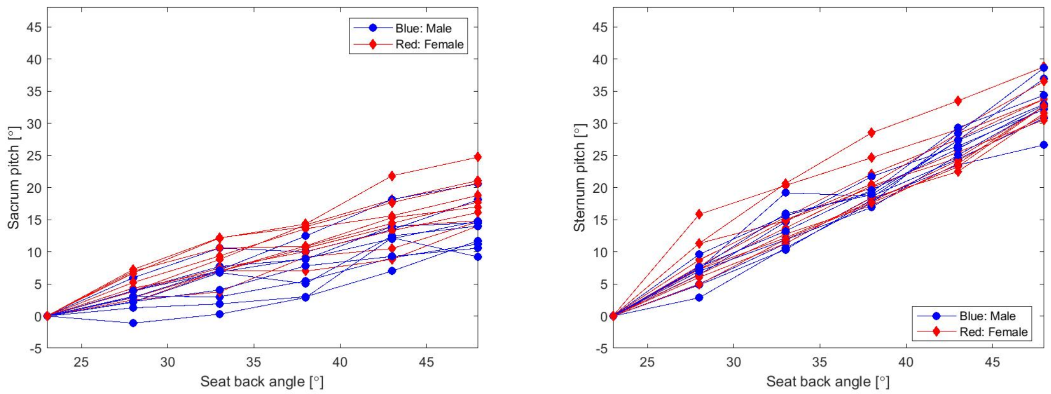

Figure 4.21: In the left figure the seat back angle vs. sacrum angle is shown. In the right figure the seat back angle vs. sternum angle is shown.

5

Discussion

The discussion is divided into the three Sections; 5.1 *Discussion of results*, 5.2 *Discussion of method and limitations* and 5.3 *Future work*.

5.1 Discussion of results

In this section, the results from the volunteer study are discussed in the following seven sections; 5.1.1 *Sacrum pitch standing and sitting*, 5.1.2 *Belt position*, 5.1.3 *Dynamic sacrum pitch*, 5.1.4 *The lap belt angle in front of iliac wing*, 5.1.5 *Correlations between pelvis rotation and slouching*, 5.1.6 *Variation of seat back angle* and 5.1.7 *Statistical models.*

5.1.1 Sacrum pitch standing and sitting

When comparing the Xsens sensor data of sacrum when sitting before and after the ride, the difference for each volunteer is low, with an average of 2°. This indicates that the sensor has probably stayed in place during the ride. Therefore, it is concluded that the change of Xsens sacrum sensor is due to volunteer moving and not the sensor moving or drifting.

When comparing sacrum pitch of standing for each volunteer the difference is larger, with an average of 5°, than the difference for sitting. This could be due to that the volunteer chose to stand in a different posture after being seated for over 40 minutes.

5.1.2 Belt position

The diagonal belt angle is similar before and after the ride, with an average of 56° in both cases. It could be possible that the diagonal belt moves during turns, acceleration and deceleration, but return to a similar angle when the car is standing still. It would be needed to do further video analysis to see the diagonal belt moves during the ride.

The lap belt has a larger difference in measured angles before and after the ride compared to the diagonal belt. This could be due to that the increase of slouching and rearward sacrum pitch affect the lap belt more than the diagonal belt.

5.1.3 Dynamic sacrum pitch

When investigating the dynamic sacrum pitch, it can be seen that in between each loop the volunteer adjusts the sitting posture by rearward rotation of pelvis. The range of sacrum pitch for each loop is approximately the same in all loops, but the starting sacrum pitch increase compared to each previous loop. The average sacrum pitch increases with travel time and the range is similar for each loop. Considering the results from standing and sitting stated in Section 5.1.1 this indicates that sacrum pitch reflects the true movement and not caused by error sources. Even though, it should be taken into consideration that some error sources could cause the range of sacrum pitch to increase or decrease slightly.

5.1.4 The lap belt angle in front of iliac wing

It was assumed that the relation between lap belt angle in front of iliac wing and sacrum pitch was constant. Since lap belt angle in front of iliac wing was measured towards soft tissue, there is a possibility that the relation is not always constant. If the volunteer leans a lot rearwards or forwards this relation could change. During the ride, the volunteers did not do any extreme movements of the body or changed the seat back angle. Thereby, this relation should be considered constant while the passenger is sitting in the car.

5.1.5 Correlation between pelvis rotation and slouching

For volunteers 5, 10 and 12 it was possible to localize the ischial tuberosities throughout the whole ride, therefore it was possible to do an analysis for how slouching and sacrum pitch relates in these cases. To analyze if the sacrum pitch and slouching are comparable, the output from Tekscan mat and Xsens sacrum sensor of volunteer 5 is compared in Figure 5.1. For both sacrum pitch and slouching the values increase with travel time. In loop 1 the volunteer mainly sits still, in loop 2 the volunteer sit still in the beginning and adjust the slouching at 9 minutes. In loop 3, the volunteer increase both sacrum pitch and slouching. In Appendix B.2 the figures for comparing sacrum pitch and slouching for volunteers 10 and 12 can be found. When considering all three volunteers, it could be concluded that the slouching and sacrum pitch mainly follow each other. It is needed to analyze more data like this to make sure the conclusion is correct.

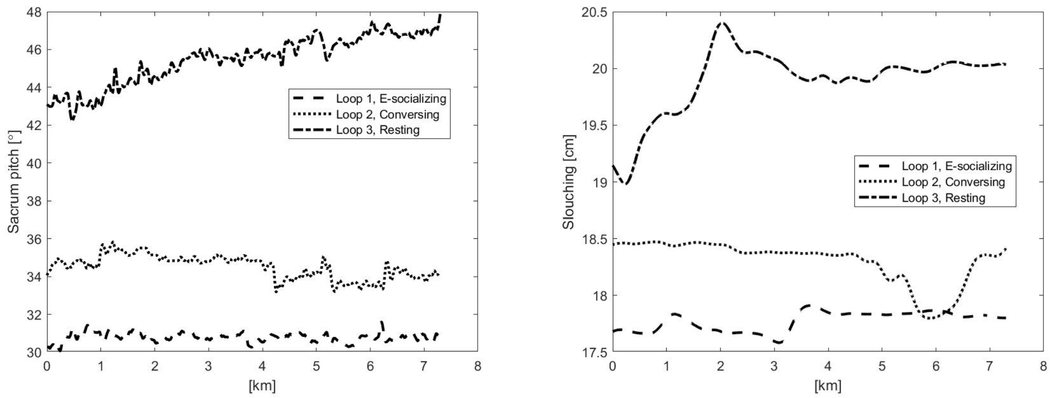

Figure 5.1: Comparing slouching and sacrum pitch for volunteer 5. The left figure shows the sacrum pitch and the right figure shows the slouching.

5.1.6 Variation of seat back angle

The seat back angles have an impact on sacrum pitch and sternum pitch which was presented in the results in Section 4.3.2. It showed that sacrum and sternum pitch increase with the seat back angle. Additionally, sternum pitch increase more than sacrum pitch. In some cases, the sternum pitch increased more than the seat back angle, this could be due to the volunteers looked up in the ceiling instead of out the windshield. Since the volunteers sat in each position for only 15 seconds, there is a risk that the volunteer would adjust their position more if it was a longer time. Additionally, since the seat cushion angle was set to minimum settings during the whole test this could have affected the sitting posture. However, the results give an indication about how the body corresponds to different seat back angles and how the sitting posture could change in future autonomous cars.

5.1.7 Statistical models

The landmarks that were used in the statistical models could not be collected in this study. At the beginning of this project, the Xsens Analyze software was intended to be used, explained in Section 2.5.1. This system could estimate the position of the person and thereby find the needed landmarks to compare with the statistical models, described in Section 2.3.1. Since it was concluded that this system was not appropriate for this study, the Xsens sensors were used independently. With this explanation, it is concluded that it is not possible to compare the sitting postures in this study to the previous developed statistical posture prediction models. The results in this study can be used as a complement when using the statistical models when positioning HBMs.

5.2 Discussion of method

In this section, the method and limitations are discussed in the following sections; 5.2.1 *The volunteers' experience of the car*, 5.2.2 *Palpation of landmarks*, 5.2.3 *Excluded volunteer*, 5.2.4 *Cameras and photos*, 5.2.5 *Activities for the volunteers and the route* and 5.2.6 *The volunteers' seat position*.

5.2.1 The volunteers' experience of the car

The volunteers' experience of the car was supposed to be as natural as possible to make them comfortable. This includes all the measurement systems that can be seen and were worn by the volunteer while sitting in the car. In the questionnaire, most of the volunteers answered that the Xsens sensors affected them the most but not to a larger extent, see Table A.2 in Appendix A.3. This indicates that the Xsens sensors did not disturb too much and that the Tekscan mat, cameras, driving style, and the car seat affected even less. If a similar volunteer study is conducted in the future, it would be preferable with an environment in the car that is even more naturalistic.

5.2.2 Palpation of landmarks

There is a risk that ASIS, the vertebrae and sternum were not identified properly on all volunteers. The palpation of these landmarks was done by one project member, she does not have any education of palpating the skeleton. This risk was assumed to be relatively low and should not affect the results that are presented in this report to a larger extent. If more complicated parts of the skeleton need to be identified in a future study, palpation by a professional would be recommended.

5.2.3 Excluded volunteer

Volunteer 17 was excluded from the results. This since he had abnormal movement when analyzing the results. He had a large variation of sacrum pitch compared to the other volunteers. By looking at the videos it could be concluded that no large movements were done, that would explain the large variation of sacrum pitch. When the Xsens sensor was taped to sternum it came off after a couple of minutes. This only happened for volunteer 17. Therefore, there is a risk that the other Xsens sensor did not stay in place on this volunteer. When comparing sacrum pitch before and after the ride while sitting still, it was noticed that volunteer 17 had by far the greatest variation.

5.2.4 Cameras and photos

Most volunteers thought the cameras did not affect them a lot except for volunteer 15, see Table A.2 in Appendix A.3. Therefore, it can be concluded that the cameras were placed in a way that did not disturb the volunteers to a larger extent, but the drawback is that the front view camera was not perpendicular to the volunteer, see Figure 3.11 in Section 3.1.7. If future video analysis will be performed this needs to be taken into consideration when measuring the dynamic diagonal belt position. This since the projected angles might be different compared to measuring projected angles with a camera placed perpendicular to the volunteer.

5.2.5 Activities for the volunteers and the route

The three activities; resting, conversing and e-socializing, were performed by each volunteer in the study. It was not possible to see any impact by activity on the sitting posture. To draw conclusions of how activity affected the volunteers' sitting posture, longer duration or different types of activities could be needed in a future study. Since as explained in Section 2.3.2 the number of adjustments of sitting posture increase over time.

5.2.6 The volunteers' seat position

The volunteers were only allowed to adjust the seat position in their personal way before the ride. It is possible that the results could be different if the initial seat position was set in another way. For example, the car seat being set to an average setting, that could have made the volunteers not change the seat position at all. Another scenario is setting the car seat to the opposite extremes to the seat position chosen in this study. This could possibly have resulted in the more rearward seat back angles and seat cushion being pushed more backward compared to the results shown in Table 4.9 in Section 4.3.1.

More specifically, most of the volunteers picked a seat back angle that is equal or close to the 23°. If it was allowed, there is a possibility that the volunteer would have changed the seat back angle during the ride. This would also have affected the results.

Another aspect is that most of the volunteers did not adjust the D-ring position. It is not possible to find out if it depends on that the volunteers do not usually adjust it, or that they preferred to have the D-ring in the highest position. Some volunteers mentioned that they rarely change the D-ring position. The position of the D-ring has an impact on the diagonal belt angle. If the initial position of the D-ring was chosen differently, this would have resulted in different diagonal belt angles.

5.3 Future work

Since the master thesis had a time limit it was not possible to analyze all the collected data. Thereby, it would be interesting in the future to analyze more of the already collected data. Firstly, the Xsens sensor data that were not covered in the results should be analyzed. Preferably, the sensors placed on the spine to investigate how the vertebrae rotate in relation to each other. Apart from that, a video analysis should be performed on the recordings from the volunteer study to be able to draw conclusions about dynamic belt position. This could be done by performing motion tracking of the photo analysis markers explained in Section 3.1.5. The route could also be more analyzed to see if there are any correlations between the type of road and sitting posture.

It should also be investigated if a statistical analysis could be performed on the collected data, to see if any correlations between the volunteer and sitting posture can be found. Additionally, the results of how much pelvis rotation and slouching are varying can be used when positioning HBMs in future crash simulations.

If a similar study is going to be conducted in the future, a larger target group would be preferred to make it possible to draw statistical conclusions of the Swedish population. To be able to confirm if the conclusion slouching and pelvis rotation correlate is correct, more results of slouching are needed. This can be done by using a Tekscan mat that can register the ischial tuberosities of all volunteers. It would also be interesting to make a longer ride where each activity has a longer travel time or let the volunteers decide the activity. It should also be investigated if other sensors than the Xsens sensors can be used that are smaller in order to avoid discomfort and to get a more naturalistic ride.

6
Conclusion

The information of sitting posture and belt position that was collected from the volunteer study was as follows. With Xsens; pitch of sacrum, sternum, L5, C7, T3 and forehead. From Tekscan mat; slouching. Belt position could not be collected with Xsens or Tekscan mat and instead photos of initial and final sitting posture were taken. Additional information of sitting posture that was collected before and after the ride were; The lap belt angle in relation to the vertical plane in front of iliac wing (lap belt angle in front of iliac wing), femur angle and horizontal distance between knee and dashboard.

It is possible to analyze pelvis rotation as a function of time and between different activities in the data from sacrum pitch and slouching. It can be seen that time has a greater impact on pelvis rotation and slouching than the activities.

In Table 4.5 it can be seen that the average range of pelvis rotation for all volunteers for the total travel time is 10°. For the three volunteers where the slouching could be analyzed, the average movement for the total travel time is 3 cm forward on the seat cushion. It was not possible to see how belt position varies as a function of time and between different activities.

Additionally, it is not possible to compare the sitting postures in the volunteer study to the previous developed statistical posture prediction models. Hopefully, the results of sitting posture produced in this report can be used as a complement to the statistical models when positioning HBMs.

In addition, conclusions can be drawn that there is a correlation between seat back angle and sitting posture, see Figures 4.20 and 4.21.

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A

Appendix Method

In this chapter the Appendix of Section 3 *Method of the volunteer study* is presented. It consists of A.1 *Check list for volunteer study*, A.2 *Anthropometric measurements*, A.3 *Questionnaire*, A.4 *Placement of Xsens sensors* and A.5 *Placement of cameras*.

A.1 Check list for volunteer study

In Figure A.1 the check list used during the volunteer study is shown. The left column explain the step, the column to the right shows which group member that was responsible for each step.

	Steps	Responsible	Check
1	Meet the volunteer and go to the rom	Both	
2	Prepare the medical tape	Emma	
3	Start Xsens sensorer	Emma	
4	Go through and sign the consent	Annika	
5	The volunteer changes clothes	Annika	
6	Weigh	Annika	
7	Measure length without shoes	Emma	
8	Measure length with shoes	Emma	
9	Measure erect sitting height	Emma	
10	Measure ear to ear	Emma	
11	Measure acromion to acromion	Emma	
12	Place the Xsens sensors on the body	Annika	
13	Place sternum and photo	Emma	
14	Place sacrum and photo	Emma	
15	Place L5 and photo	Emma	
16	Place C7 and photo	Emma	
17	Place T3 and photo	Emma	
18	Place forehead and photo	Emma	
19	Add photo analysis markers on sacrum	Annika	
20	Add small white balls to the shoulders	Annika	
21	Photo back and forth	Emma	
22	Go to the car	Both	
23	Check Tekscan is in place	Both	
24	Ask the volunteer to change seat parameters	Annika	
25	Verify the seat parameters	Emma	
26	Measure seat back angle	Emma	
27	Measure seat cushion in x-axis	Emma	
28	Measure the D-ring	Emma	
29	Explain standing to sitting	Annika	
30	Record standing to sitting	Annika	
31	Lap belt angle at iliac wing was measured and photo	Emma	
32	Measure knee to dashbord	Emma	
33	Femur angle	Emma	
34	Add photo analysis markers on the belt	Emma	
35	Photos of volunteer's sitting posture	Emma	
36	Attach the car sensors	Annika	
37	Attach the car tracker	Annika	
38	Connect the computer to the measuring system	Annika	
39	Align cameras	Emma	
40	Start cameras	Emma	
41	Start the car tracker	Annika	
42	Start the Tekscan mat	Annika	
43	Set sensitivity of the Tekscan mat	Annika	
44	Volunteer push their Ischial tuberosities in the seat	Annika	
45	Sync the measuring system	Both	
46	Loop 1	Emma	
47	Sync the measuring system	Both	
48	Loop 2	Annika	
49	Sync the measuring system	Both	
50	Loop 3	Annika	
51	Stopp Xsens	Annika	
52	Volunteer push their Ischial tuberosities in the seat	Annika	
53	Stop the Tekscan mat	Annika	
54	Stop the car tracker	Annika	
55	Stop camras	Emma	
56	Photos of volunteer's sitting posture	Emma	
57	Measure knee to dashbord	Emma	
58	Femur angle	Emma	
59	Lap belt angle at iliac wing was measured	Emma	
60	Record standing to sitting	Annika	
61	Start Tekscan	Annika	
62	Sync the measuring system	Both	
63	Set seat back angle to, 23, 28, 33, 38, 43, 48 - 15sec	Annika	
64	Stop Xsens and tekscan	Annika	
65	Check Tekscan is in place	Emma	
66	Go back to the room	Both	
67	Remove the Xsens sensorer	Annika	
68	the volunteer fill out the questionnaire	Emma	
69	Save the data	Both	

Figure A.1: The checklist used in the volunteer study.

A.2 Anthropometric measurements

Below are the room and instruments used when collecting the anthropometric measurements. In Figure A.2, the room where the anthropometric measurements were collected and the instrument used to measure ear to ear. Figure A.3 shows how volunteer height, volunteer height without shoes, as well as erect sitting height were measured.

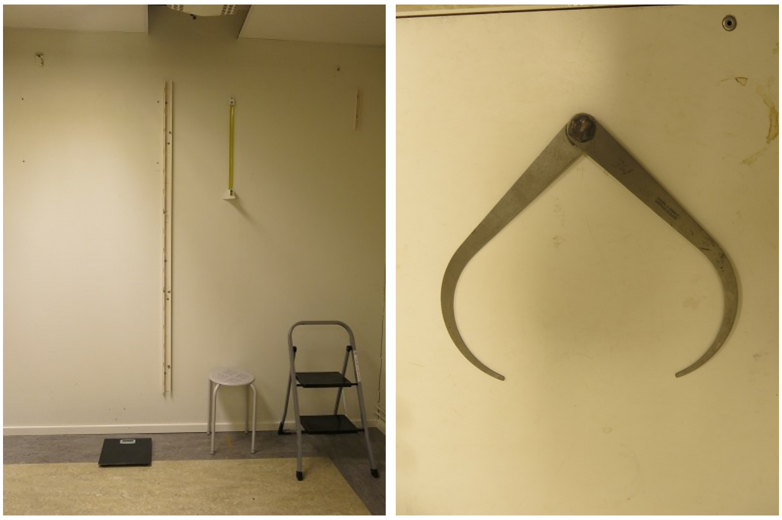

Figure A.2: To the left: the room where the anthropometric measurements were collected. To the right: The instrument that was used to measure ear to ear.

Figure A.3: How volunteer height and erect sitting height were measured.

A.2.1 Collected anthropometric measurements

Table A.1 shows the collected anthropometric measurements collected for each volunteer.

Volunteer	Age [years]	Gender	Volunteer height [cm]	Volunteer height with shoes [cm]	Erect sitting height [cm]	Ear to Ear [cm]	Acromion to Acromion [cm]	Weight [kg]	BMI
Volunteer 1	27	Male	180.5	182.5	92,5	15.5	40.5	88.7	27.2
Volunteer 2	27	Male	176	178	90	14	42	73	23.7
Volunteer 3	27	Male	180	182	88.5	14	41	88	27.1
Volunteer 4	24	Female	169	172.5	86	14	38	72	25.2
Volunteer 5	28	Female	176	179.5	89.5	12.5	37	57.5	18.6
Volunteer 6	26	Male	169	170.5	83	14.5	41	66	23.1
Volunteer 7	24	Female	172	174	87.5	13	37	69.5	23.6
Volunteer 8	26	Male	180	182	90,5	14.5	40	76.3	23.5
Volunteer 9	27	Female	172	173.5	84.5	13.5	38	63.9	21.6
Volunteer 10	26	Female	169.5	172.5	80.5	13.5	37	62	21.6
Volunteer 11	19	Female	165	167.5	84,5	13.5	34	67.3	24.7
Volunteer 12	24	Female	185.5	188	95.5	14	39	73.6	21.4
Volunteer 13	25	Female	168.5	170.5	85	14	38.5	72.5	25.5
Volunteer 14	24	Male	189	192	91.5	14	43	89.1	24.9
Volunteer 15	25	Female	160	162.5	84.5	15	36	61	23.8
Volunteer 16	25	Male	185	187	89.5	14.5	42	73.3	21.5
Volunteer 18	22	Male	180	181.5	93	14.5	42	73.8	22.8
Volunteer 19	20	Male	179.5	181.5	89.5	14	39	77.5	24.1
Volunteer 20	20	Female	162.5	163.5	82	13	37	57	21.6

Table A.1: Anthropometric measurements

A.3 Questionnaire

On the next page, the questionnaire that each volunteer filled in is shown. In Table A.2 a summary of the answers of how the measurement systems affected the behaviour of the volunteers is presented.

Volunteer	All measurement system together	The driving	Cameras	The car seat	The Xsens sensor
Volunteer 1	2	1	2	1	2
Volunteer 2	2	1	2	1	2
Volunteer 3	1	1	1	1	3
Volunteer 4	1	1	1	1	1
Volunteer 5	2	1	2	1	1
Volunteer 6	3	1	1	1	3
Volunteer 7	2	1	1	1	2
Volunteer 8	3	1	3	1	3
Volunteer 9	2	2	1	1	2
Volunteer 10	2	1	1	1	2
Volunteer 11	2	1	1	1	3
Volunteer 12	2	1	1	1	3
Volunteer 13	3	1	1	1	4
Volunteer 14	2	1	1	1	2
Volunteer 15	3	1	4	2	4
Volunteer 16	2	2	1	2	3
Volunteer 17	3	1	1	1	3
Volunteer 18	2	2	1	2	2
Volunteer 19	5	3	1	3	4
Volunteer 20	2	1	1	2	2

Table A.2: The questions that was asked how much the different the measurement system affect their behaviour i the car. The volunteer answered with a number between 1 (didn't affect) and 6(affected a lot).

Bilaga 5

Datum/Date: ________________

Frågor vid volontärprov/Questions for volunteer test

Namn/Name: ____

Födelseår/Year of birth: ____

Yrke/Profession: ____

Biologiskt Kön/Biological Sex: ☐ Man/Male ☐ Kvinna/Female

1. Hur du körkort/Do you have a driving license?

☐ Ja/Yes ☐ Nej/No

2. Hur ofta kör eller åker du bil?/How often do you drive or travel by car?

☐ Varje dag/Everyday ☐ Flera gånger per vecka/Several times per week

☐ Varje vecka/Every week ☐ Varje månad/Every month ☐ Mer sällan/Less frequently

3. Vilken är din vanliga roll när du åker bil?/What is your usual role when traveling by car?

☐ Passagerare/Passenger ☐ Förare/Driver

4. Vilken(a) bilar brukar du köra eller åka?/What car(s) do you usually drive or travel in?

____

5. Är du van att åka i Volvo XC90?/Are you used to travel in Volvo XC90?

☐ Ingen/No ☐ Lite/Little

☐ Ganska mycket/Pretty much ☐ Mycket/Much

6. Hur långt åker du per år (uppskattningsvis)? / How long distance do you travel per year (approximately)? ____________________ km

7. Hur påverkade mätinstrumenten ditt normala beteende i bilen, på en skala 1 (påverkade inget) till 6 (påverkade mycket)?/ How did the measurement systems affect your normal behaviour in the car, on a scale from 1 (didn't affect) to 6 (affected a lot)?

1 2 3 4 5 6

8a. Hur påverkade körningen ditt normala beteende i bilen, på en skala 1 till 6?/ How did the driving affect your normal behaviour in the car, on a scale from 1 to 6?

1 2 3 4 5 6

Bilaga 5

8b. Några kommentarer om körningen?/Any comments about the driving?

____

____

9a. Hur påverkade kamerorna ditt normala beteende i bilen, på en skala 1 till 6?/ How did the cameras affect your normal behaviour in the car, on a scale from 1 to 6?

1 2 3 4 5 6

9b. Några kommentarer om kamerorna?/Any comments about the cameras?

____

____

10a. Hur påverkade bilstolen ditt normala beteende i bilen, på en skala 1 till 6?/ How did the car seat affect your normal behaviour in the car, on a scale from 1 to 6?

1 2 3 4 5 6

10b. Några kommentarer om bilstolen?/Any comments about the car seat?

____

____

11a. Hur påverkade sensorerna ditt normala beteende i bilen, på en skala 1 till 6?/ How did the car sensors your normal behaviour in the car, on a scale from 1 to 6?

1 2 3 4 5 6

11b. Några kommentarer om sensorerna?/Any comments about the sensors?

____

____

12. Om sensorerna rörde på sig under testet, vilka sensorer var det?/If some sensors moved during the test, which of the sensors was it?

____

____

13. Några andra kommentarer?/Any other comments?

____

____

A.4 Placement of Xsens sesnors

In the Figures A.4, A.5, A.6 and A.7 the placement of the Xsens sensors are shown. It can be seen that they are attached with medical tape, except for one sensor placed with a headband. The sensor on sternum had a photo analysis marker on top of it.

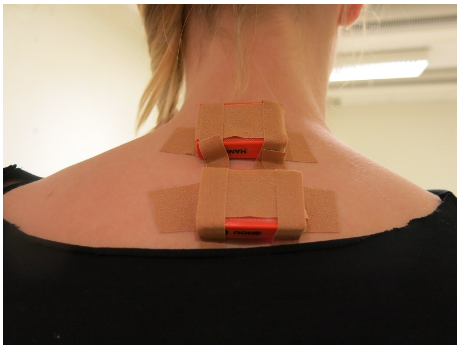

Figure A.4: The Xsens sensors placed on C7 and T3

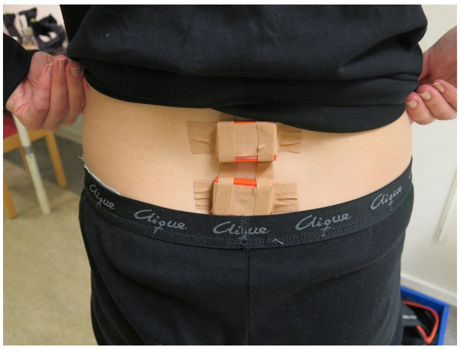

Figure A.5: The Xsens sensors placed on sacrum and L5.

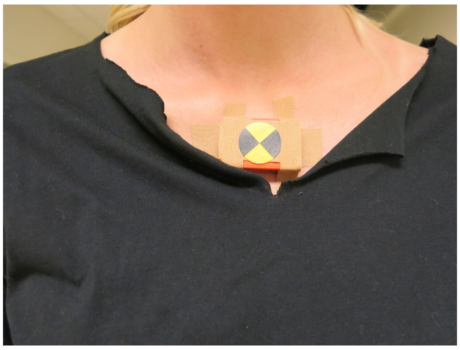

Figure A.6: The Xsens sensor placed on sternum.

Figure A.7: The Xsens sensor placed on forehead.

A.5 Placement of Cameras

In Figures A.8, A.9 and A.10 the placement of the camera when taking photos are shown. Figure A.8 show the camera's position when taking side view and side view with crossed arms. Figure A.9 shows the position of the camera when taking photo of the side view with focus on diagonal belt wrapping. In Figure A.10, the position when taking the front view photo is shown.

Figure A.8: The placement of camera when taking side view and side view with crossed arms photos

Figure A.9: The placement of camera when taking side view with focus on diagonal belt photos

Figure A.10: The placement of camera when taking front view photos

B

Appendix Results

In this chapter the Appendix of Section 4 *Results* is presented. This chapter consists of B.1 *Volunteer 12*, B.2 *Slouching*, B.3 *Sacrum rotation of each volunteer*, B.4 *The lap belt angle in front of iliac wing* and B.5 *Variation of seat back angle*.

B.1 Volunteer 12

In this section the data collected from all Xsens sensors is presented. The result is presented loop by loop.

B.1.1 Loop 1

In Figure B.1 to B.7 the data from Xsens sensors of loop 1 is shown for volunteer 12. The data from the rest of the volunteers can be found in an external hard drive. The left figure show the output data from the Xsens sensor. The middle figure show the Xsens sensor output data together with the car Xsens sensor. The right figure show the range of angles from the Xsens sensor output.

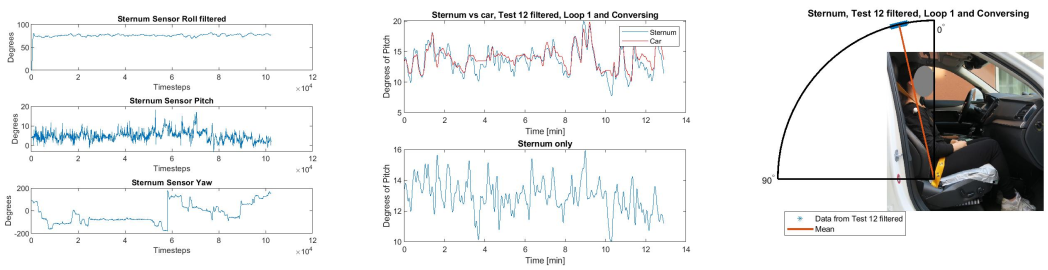

Figure B.1: Sternum Xsens sensor output for volunteer 12.

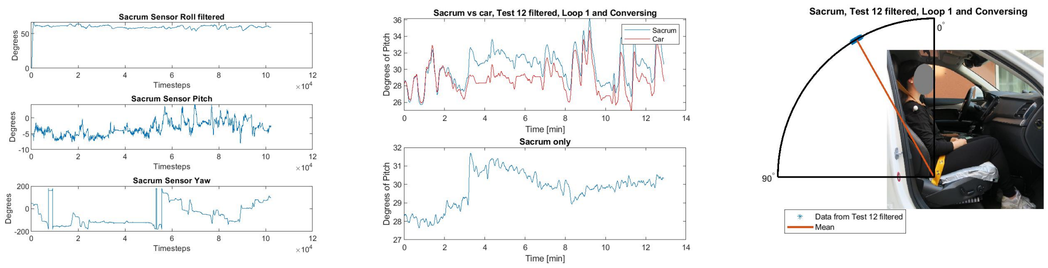

Figure B.2: Sacrum Xsens sensor output for volunteer 12.

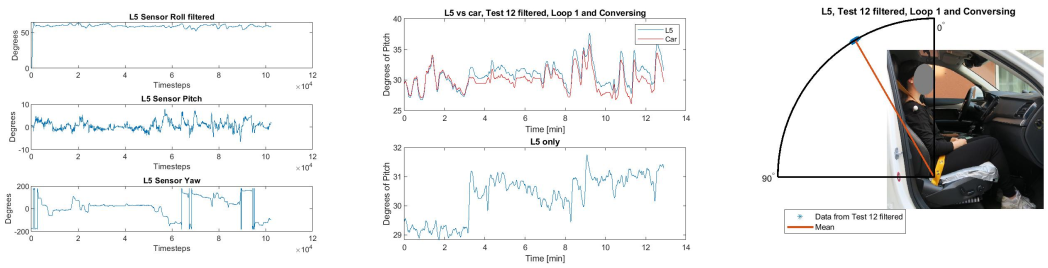

Figure B.3: L5 Xsens sensor output for volunteer 12.

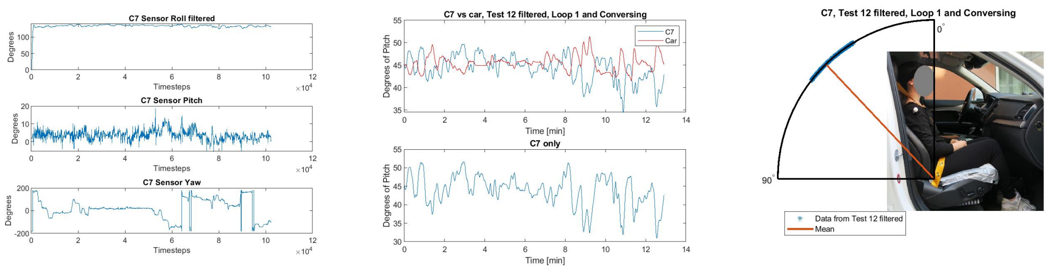

Figure B.4: C7 Xsens sensor output for volunteer 12.

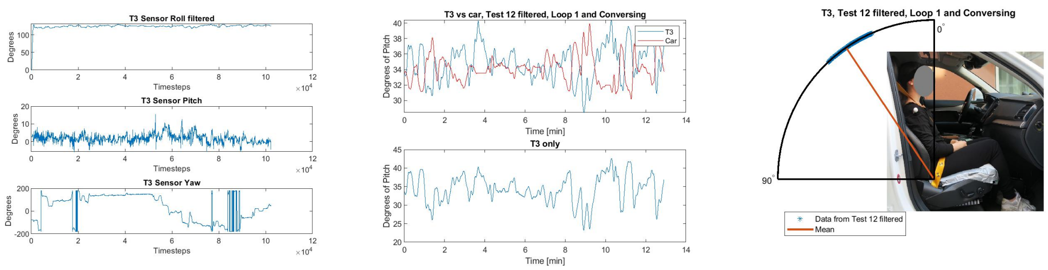

Figure B.5: T3 Xsens sensor output for volunteer 12.

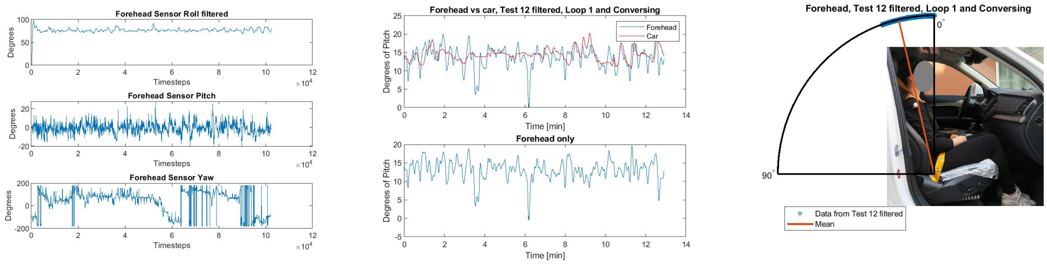

Figure B.6: Forehead Xsens sensor output for volunteer 12.

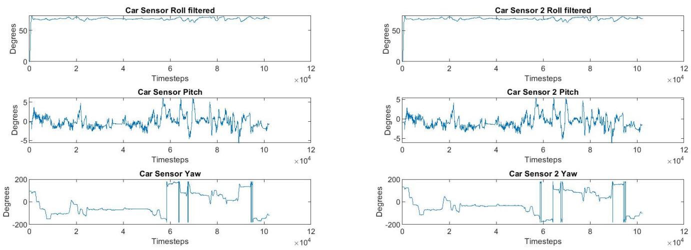

Figure B.7: Car sensors Xsens sensor output for volunteer 12.

B.1.2 Loop 2

In Figure B.8 to B.14 the data from Xsens sensors of loop 2 is shown for volunteer 12. The data from the rest of the volunteers can be found in an external hard drive. The left figure show the output data from the Xsens sensor. The middle figure show the Xsens sensor output data together with the car Xsens sensor. The right figure show the range of angles from the Xsens sensor output.

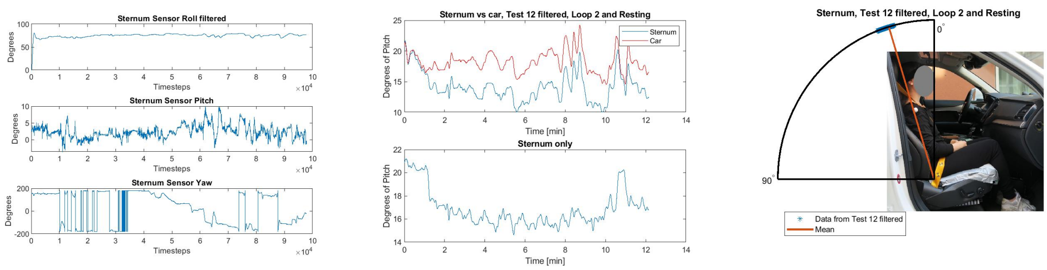

Figure B.8: Sternum Xsens sensor output for volunteer 12.

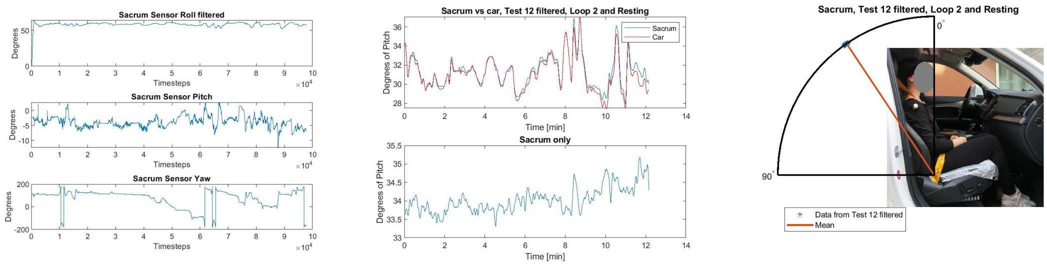

Figure B.9: Sacrum Xsens sensor output for volunteer 12.

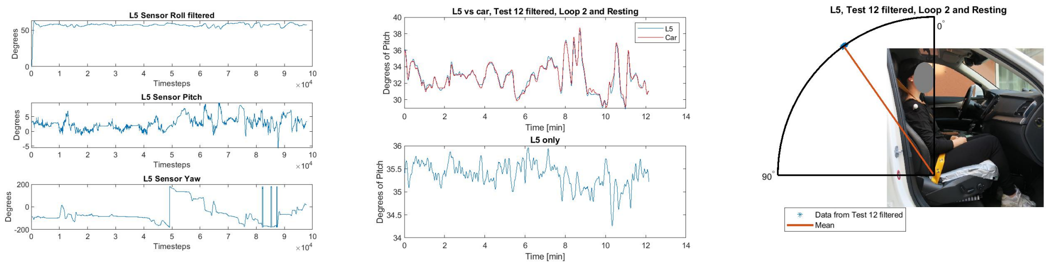

Figure B.10: L5 Xsens sensor output for volunteer 12.

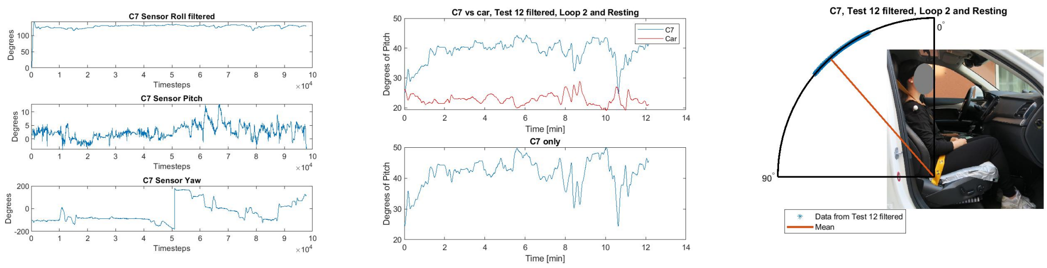

Figure B.11: C7 Xsens sensor output for volunteer 12.

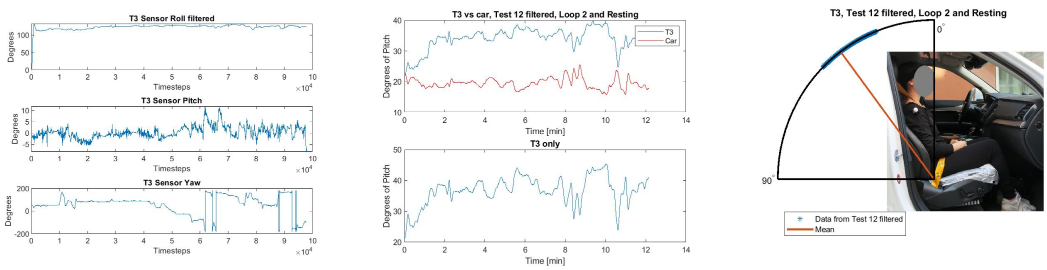

Figure B.12: T3 Xsens sensor output for volunteer 12.

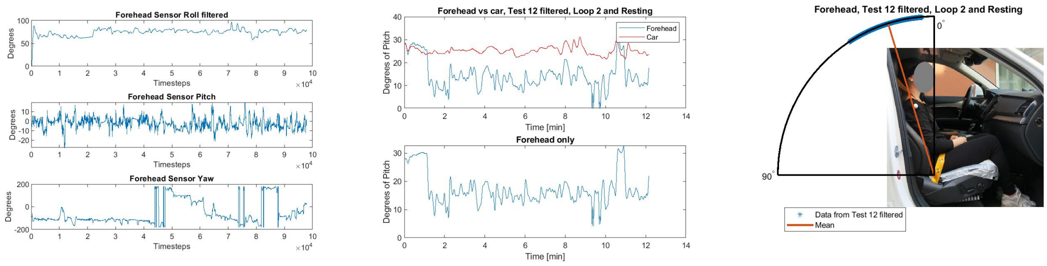

Figure B.13: Forehead Xsens sensor output for volunteer 12.

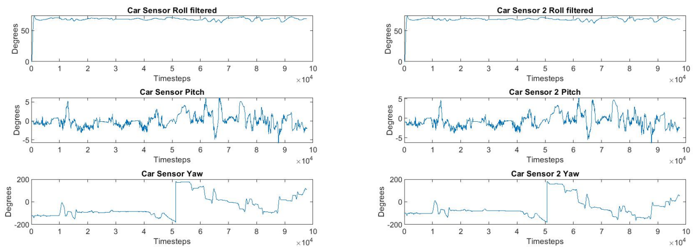

Figure B.14: Car sensors Xsens sensor output for volunteer 12.

B.1.3 Loop 3

In Figure B.15 to B.21 the data from Xsens sensors of loop 3 is shown for volunteer 12. The data from the rest of the volunteers can be found in an external hard drive. The left figure show the output data from the Xsens sensor. The middle figure show the Xsens sensor output data together with the car Xsens sensor. The right figure show the range of angles from the Xsens sensor output.

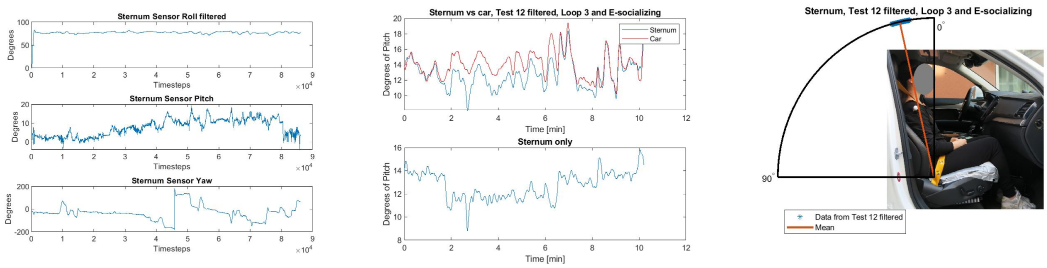

Figure B.15: Sternum Xsens sensor output for volunteer 12.

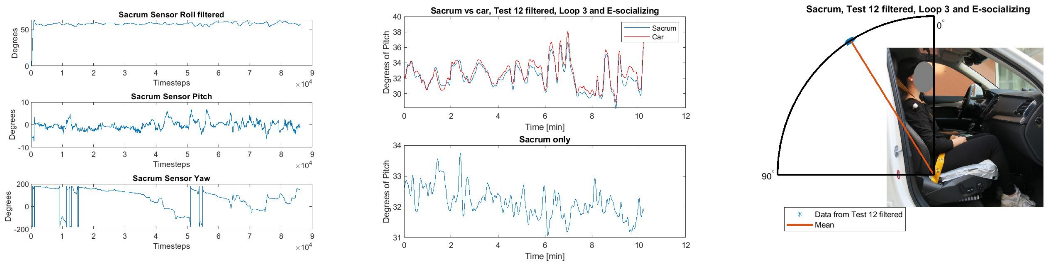

Figure B.16: Sacrum Xsens sensor output for volunteer 12.

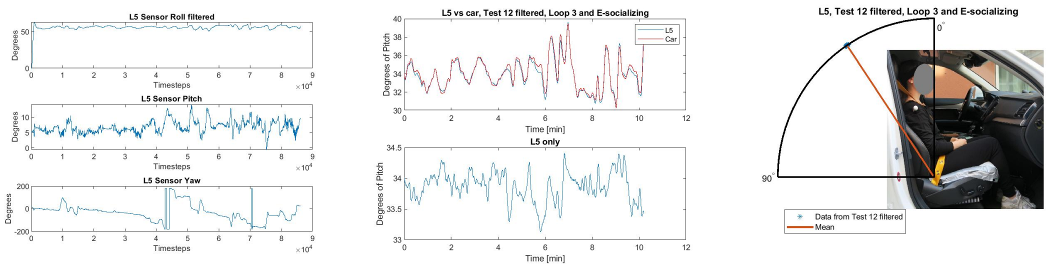

Figure B.17: L5 Xsens sensor output for volunteer 12.

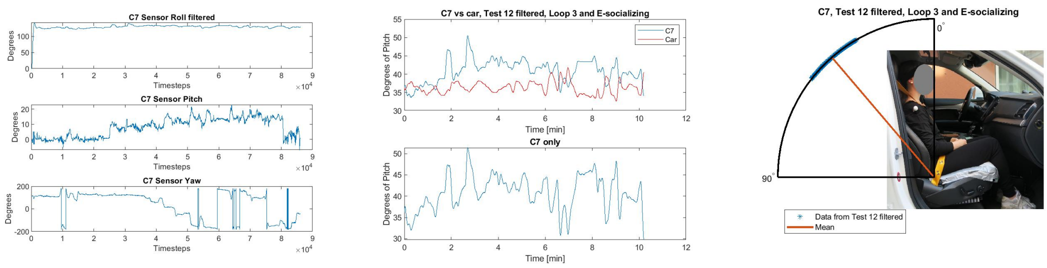

Figure B.18: C7 Xsens sensor output for volunteer 12.

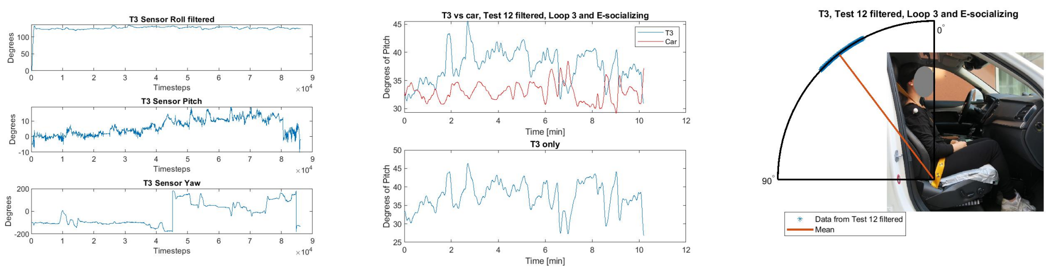

Figure B.19: T3 Xsens sensor output for volunteer 12.

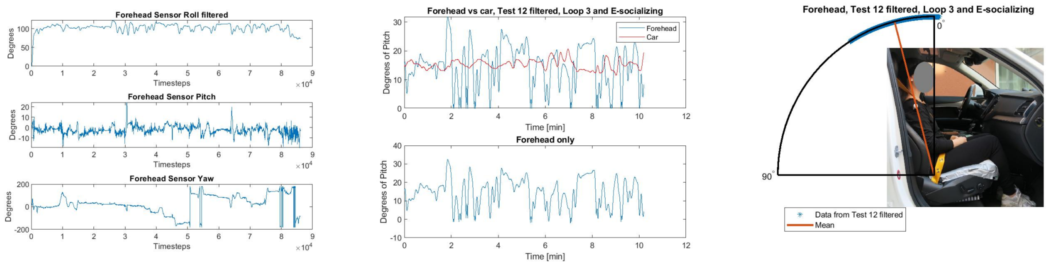

Figure B.20: Forehead Xsens sensor output for volunteer 12.

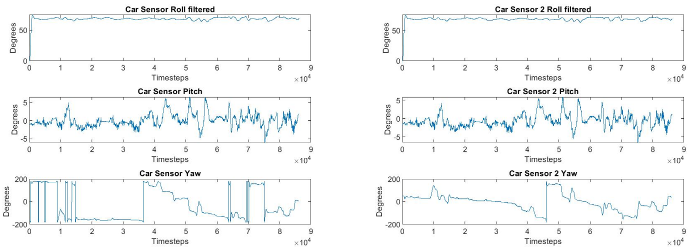

Figure B.21: Car sensors Xsens sensor output for volunteer 12.

B.2 Slouching

In this section, the results from volunteer 10 and 12 are shown when comparing sacrum pitch and slouching, see Figures B.22 and B.23.

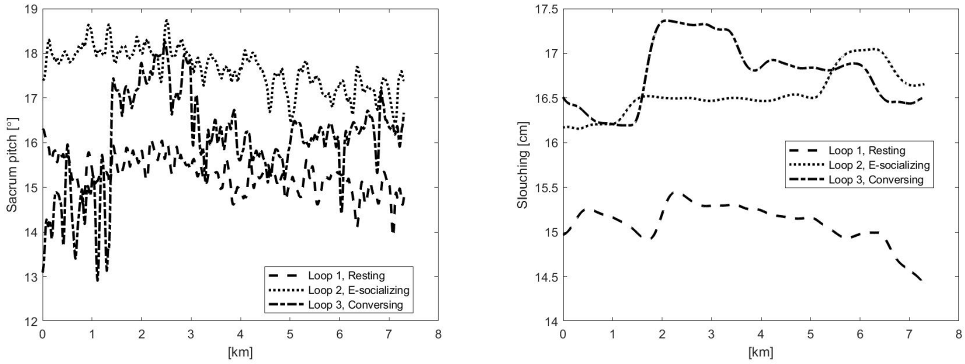

Figure B.22: Comparing slouching and sacrum pitch for volunteer 10

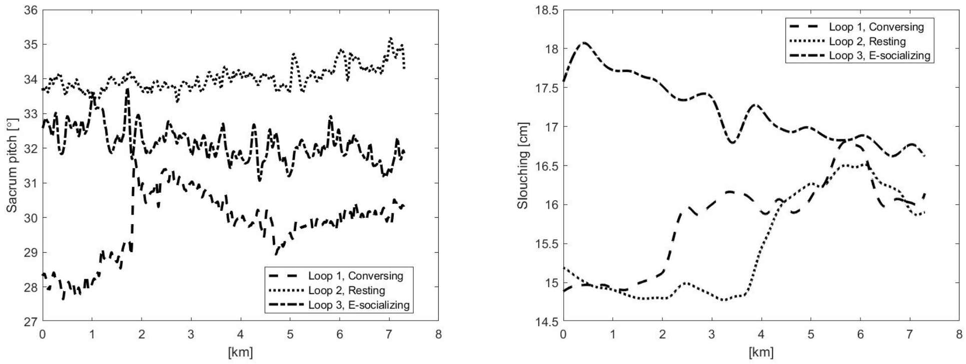

Figure B.23: Comparing slouching and sacrum pitch for volunteer 12.

B.2.1 Volunteer 12

In Figures B.24 and B.25, the movement of ischial tuberosities for volunteer 12 is shown for each loop.

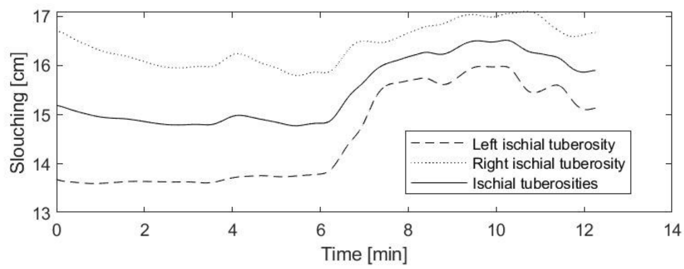

Figure B.24: The movement of ischial tuberosities, analyzed in TEMA, loop 2 for Volunteer 12.

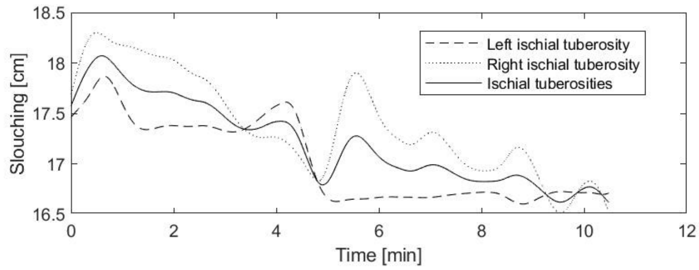

Figure B.25: The movement of ischial tuberosities, analyzed in TEMA, loop 3 for Volunteer 12.

B.3 Sacrum pitch of each volunteer

In Table B.1, the sacrum pitch of all male volunteers is shown. The table explain the average, maximum, minimum, range and travel time for each activity and loop. In Figures B.26, B.27 and B.28 the sacrum pitch of male for each loop can be found and in Figures B.29, B.30 and B.31 the sacrum pitch change for each activity for men are shown.

Volunteer	Loop	Activity	Average	Max	Min	Range	Travel time [min]
Volunteer 1	1	Conversing	28.5°	30.1°	25.1°	5.0°	15.5
Volunteer 1	2	E-socializing	33.3°	44.2°	27.1°	17.1°	13.8
Volunteer 1	3	Resting	36.4°	37.9°	34.4°	3.5°	14.9
Volunteer 1	total	-	32.7°	44.2°	25.1°	19.1°	44.2
Volunteer 2	1	E-socializing	31.3°	32.5°	30.0°	2.5°	12.4
Volunteer 2	2	Resting	32.2°	34.9°	30.5°	4.4°	12.7
Volunteer 2	3	Conversing	35.6°	36.5°	34.6°	1.9°	10.6
Volunteer 2	total	-	33.0°	36.5°	30.0°	6.5°	35.7
Volunteer 3	1	Resting	22.4°	23.4°	21.3°	2.1°	13.3
Volunteer 3	2	Conversing	20.4°	22.2°	16.7°	5.5°	14.3
Volunteer 3	3	E-socializing	22.2°	22.8°	21.4°	1.4°	17.0
Volunteer 3	total	-	21.7°	23.4°	16.7°	6.7°	44.6
Volunteer 6	1	Resting	27.4°	28.2°	26.5°	1.7°	12.7
Volunteer 6	2	E-socializing	27.5°	28.6°	26.5°	2.1°	9.9
Volunteer 6	3	Conversing	27.9°	28.8°	26.9°	1.9°	10.8
Volunteer 6	total	-	27.6°	28.8°	26.5°	2.3°	33.4
Volunteer 8	1	E-socializing	31.3°	34.3°	27.7°	6.6°	12.7
Volunteer 8	2	Conversing	32.1°	36.5°	28.6°	7.9°	10.6
Volunteer 8	3	Resting	37.5°	43.4°	36.1°	7.2°	11.8
Volunteer 8	total	-	33.6°	43.4°	27.7°	15.7°	35.1
Volunteer 14	1	Conversing	30.4°	32.5°	29.1°	3.4°	12.9
Volunteer 14	2	Resting	39.4°	42.0°	32.1°	9.9°	10.6
Volunteer 14	3	E-socializing	45.5°	49.4°	41.3°	8.1°	11.5
Volunteer 14	total	-	38.4°	49.4°	29.1°	20.3°	35
Volunteer 16	1	Resting	35.0°	36.3°	32.7°	3.6°	11.4
Volunteer 16	2	Conversing	39.0°	40.9°	37.0°	3.9°	13.1
Volunteer 16	3	E-socializing	44.5°	47.6°	37.4°	10.2°	12.3
Volunteer 16	total	-	39.5°	47.6°	32.7°	14.9°	36.8
Volunteer 18	1	E-socializing	37.8°	40.4°	34.9°	5.5°	11.8
Volunteer 18	2	Conversing	37.0°	37.8°	36.3°	1.5°	10.9
Volunteer 18	3	Resting	42.1°	43.6°	39.1°	4.5°	11.0
Volunteer 18	total	-	39.0°	43.6°	34.9°	8.7°	33.7
Volunteer 19	1	Conversing	25.4°	26.8°	23.1°	3.7°	12.1
Volunteer 19	2	E-socializing	25.8°	27.1°	23.1°	4.0°	12.3
Volunteer 19	3	Resting	28.2°	32.1°	26.1°	6.0°	16.2
Volunteer 19	total	-	26.5°	32.1°	23.1°	9.0°	40.6

Table B.1: Sacrum rotation of male.

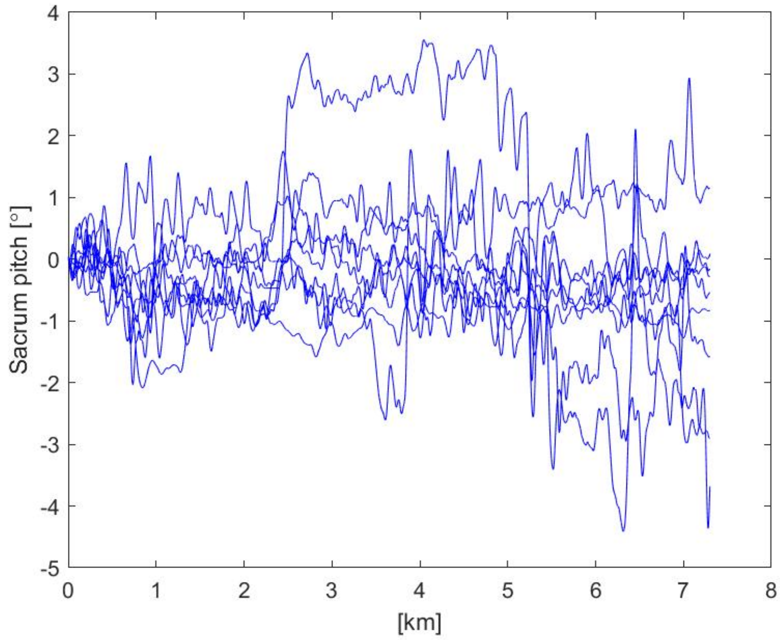

Figure B.26: The Xsens sacrum sensor output for loop 1, male.

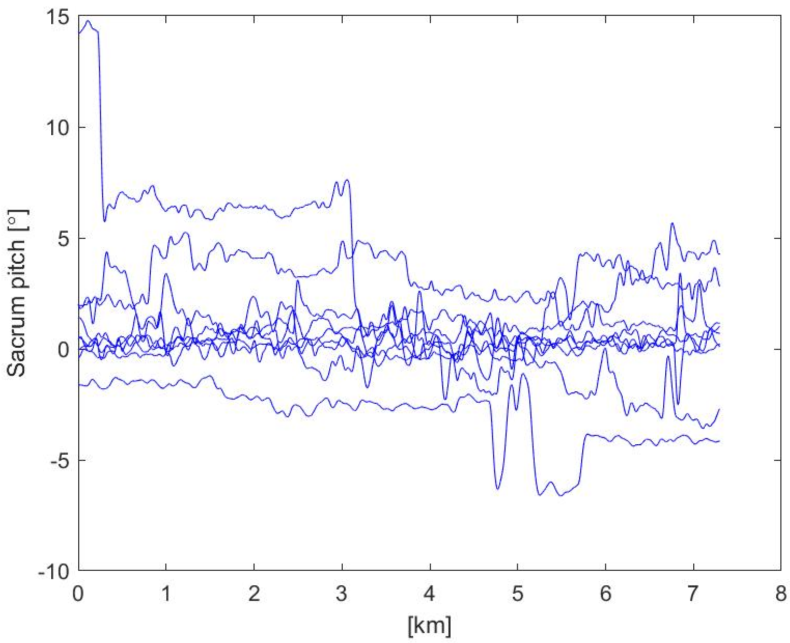

Figure B.27: The Xsens sacrum sensor output for loop 2, male.

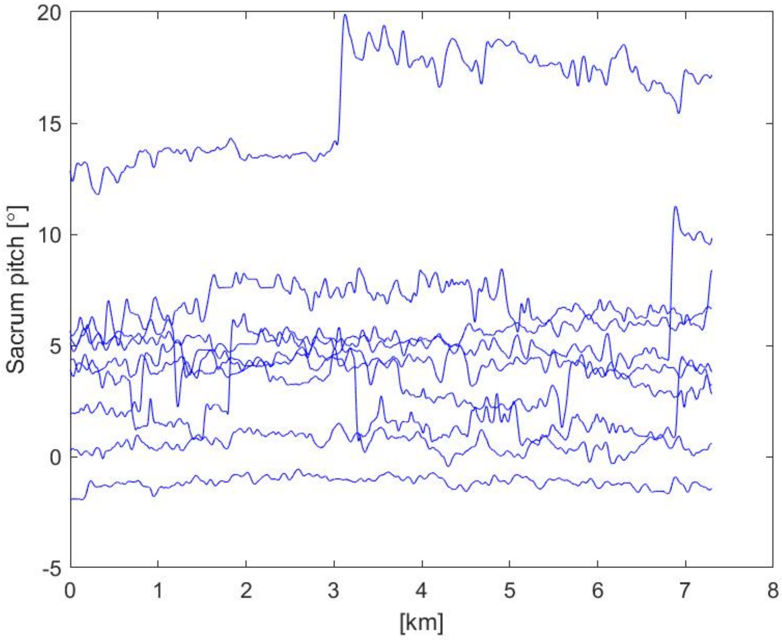

Figure B.28: The Xsens sacrum sensor output for loop 3, male.

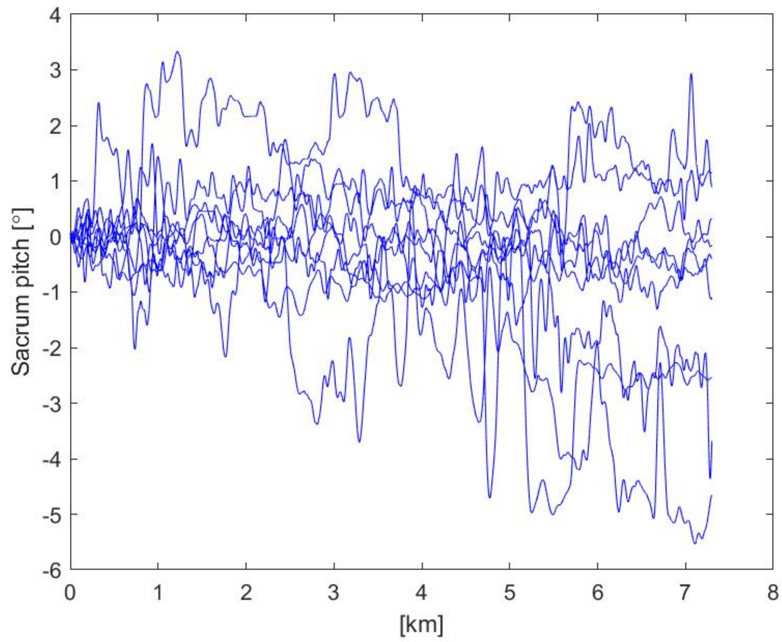

Figure B.29: The Xsens sacrum sensor output for conversing, male.

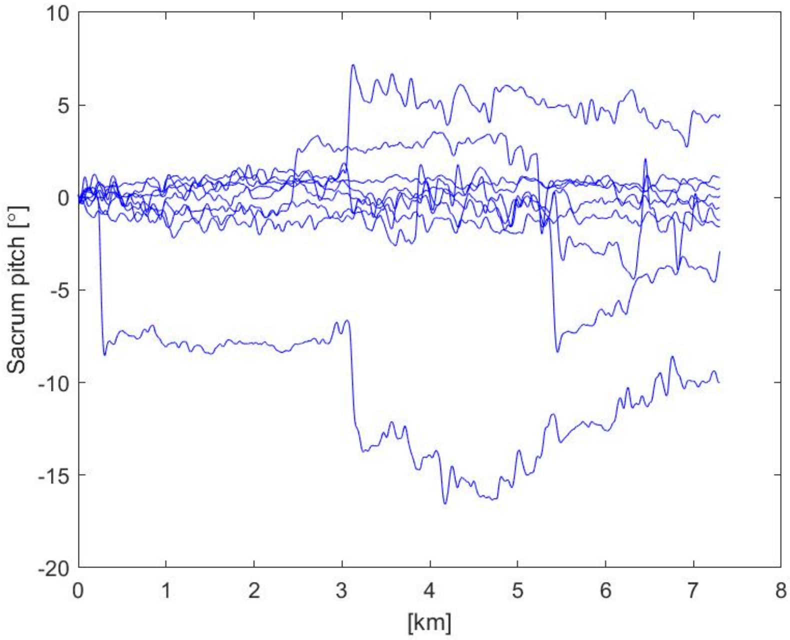

Figure B.30: The Xsens sacrum sensor output for e-socializing, male.

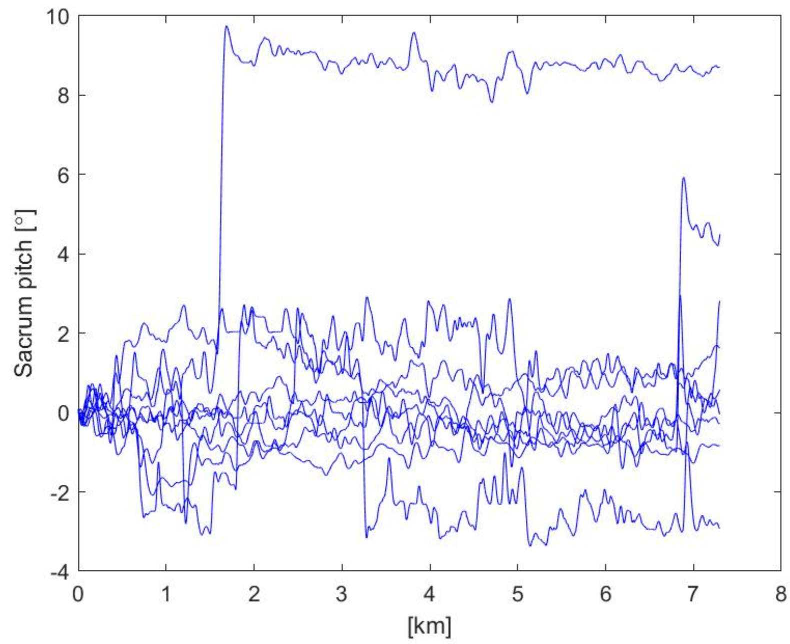

Figure B.31: The Xsens sacrum sensor output for resting, male.

In Table B.2, the sacrum pitch of all female volunteers is shown. The table explain the average, maximum, minimum, range and travel time for each activity and loop. In Figures B.32, B.33 and B.34 the sacrum pitch of male for each loop can be found and in Figures B.35, B.36 and B.37 the sacrum pitch change for each activity for men are shown.

Volunteer	Loop	Activity	Average	Max	Min	Range	Travel time [min]
Volunteer 4	1	Conversing	33.7°	34.7°	31.8°	2.9°	16.4
Volunteer 4	2	E-socializing	32.9°	34.9°	30.8°	4.1°	13.1
Volunteer 4	3	Resting	36.9°	38.1°	34.7°	3.4°	11.3
Volunteer 4	total	-	34.5°	38.1°	30.8°	7.3°	40.8
Volunteer 5	1	E-socializing	30.8°	31.6°	30.1°	1.5°	12.0
Volunteer 5	2	Conversing	34.5°	35.8°	33.2°	2.6°	11.7
Volunteer 5	3	Resting	45.5°	47.9°	42.2°	5.7°	11.1
Volunteer 5	total	-	36.9°	47.9°	30.1°	17.8°	34.8
Volunteer 7	1	Resting	38.5°	39.3°	37.6°	1.7°	10.6
Volunteer 7	2	Conversing	42.4°	43.8°	40.1°	3.7°	11.9
Volunteer 7	3	E-socializing	44.8°	45.8°	43.8°	2.0°	11.0
Volunteer 7	total	-	41.9°	45.8°	37.6°	8.2°	33.5
Volunteer 9	1	Conversing	29.8°	30.8°	28.9°	1.9°	13.8
Volunteer 9	2	E-socializing	30.0°	30.6°	29.5°	1.1°	9.9
Volunteer 9	3	Resting	29.8°	30.8°	28.6°	2.2°	10.2
Volunteer 9	total	-	29.9°	30.8°	28.6°	2.2°	33.9
Volunteer 10	1	Resting	15.3°	16.3°	13.9°	2.4°	10.5
Volunteer 10	2	E-socializing	17.7°	18.7°	16.4°	2.3°	9.7
Volunteer 10	3	Conversing	16.1°	18.3°	12.9°	5.4°	11.2
Volunteer 10	total	-	16.4°	18.7°	12.9°	5.8°	31.4
Volunteer 11	1	E-socializing	21.6°	22.8°	19.4°	3.4°	10.2
Volunteer 11	2	Resting	21.0°	22.0°	20.3°	1.7°	12.4
Volunteer 11	3	Conversing	25.6°	26.2°	24.9°	1.3°	13.5
Volunteer 11	total	-	22.7°	26.2°	19.4°	6.8°	36.1
Volunteer 12	1	Conversing	29.8°	31.7°	27.6°	4.1°	12.9
Volunteer 12	2	Resting	34.0°	35.2°	33.3°	1.9°	12.1
Volunteer 12	3	E-socializing	32.1°	33.7°	31.1°	2.6°	10.2
Volunteer 12	total	-	32.0°	35.2°	27.6°	7.6°	35.2
Volunteer 13	1	E-socializing	26.3°	28.0°	24.3°	3.7°	11.2
Volunteer 13	2	Resting	29.3°	30.3°	28.3°	2.0°	11.6
Volunteer 13	3	Conversing	30.3°	31.4°	29.4°	2.0°	11.3
Volunteer 13	total	-	28.6°	31.40°	24.3°	7.1°	34.1
Volunteer 15	1	Resting	27.8°	28.7°	26.6°	2.1°	10.8
Volunteer 15	2	Conversing	28.6°	30.1°	27.1°	3.0°	10.8
Volunteer 15	3	E-socializing	28.1°	36.0°	23.8°	12.2°	10.1
Volunteer 15	total	-	28.2°	36.0°	23.8°	12.2°	31.7
Volunteer 20	1	E-socializing	32.4°	34.5°	30.2°	4.3°	11.5
Volunteer 20	2	Conversing	34.5°	35.2°	32.8°	2.4°	10.3
Volunteer 20	3	Resting	35.8°	38.2°	33.7°	4.5°	10.3
Volunteer 20	total	-	34.2°	38.2°	30.2°	8.0°	32.1

Table B.2: Sacrum rotation of female

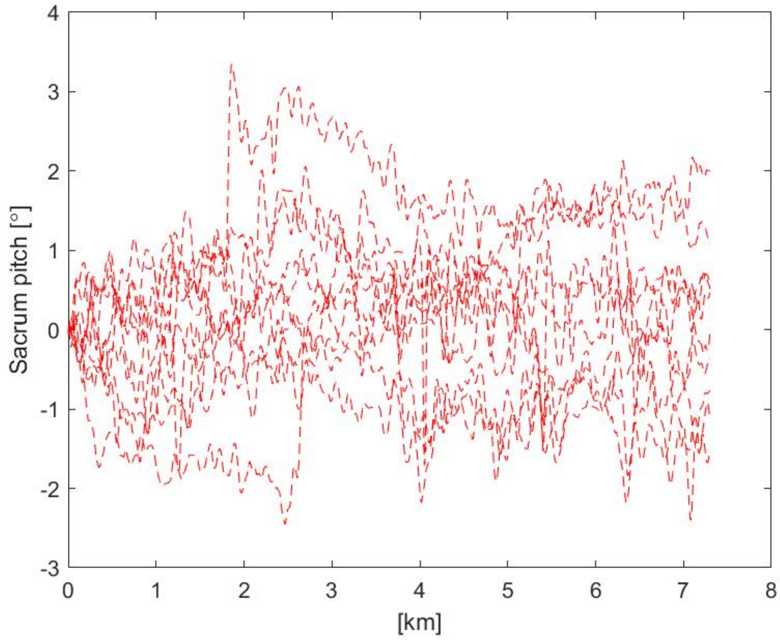

Figure B.32: The Xsens sacrum sensor output for loop 1, female.

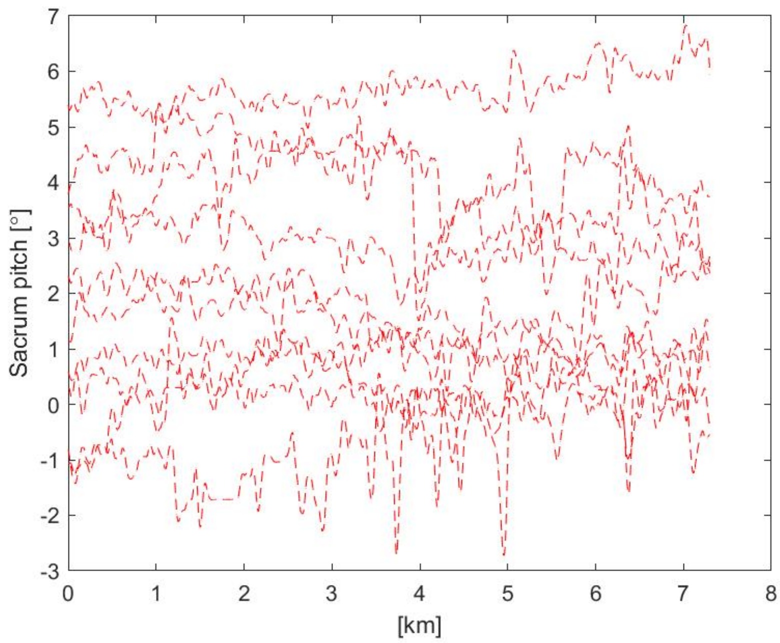

Figure B.33: The Xsens sacrum sensor output for loop 2, female.

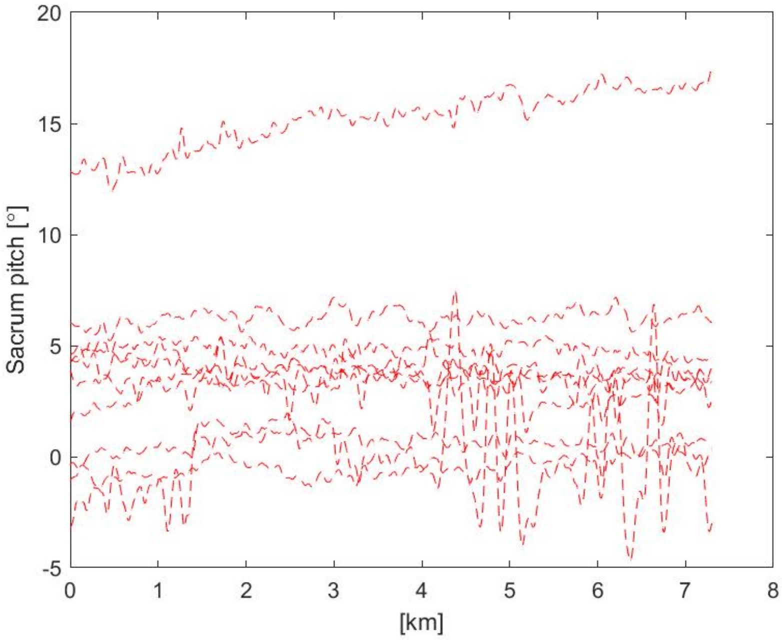

Figure B.34: The Xsens sacrum sensor output for loop 3, female.

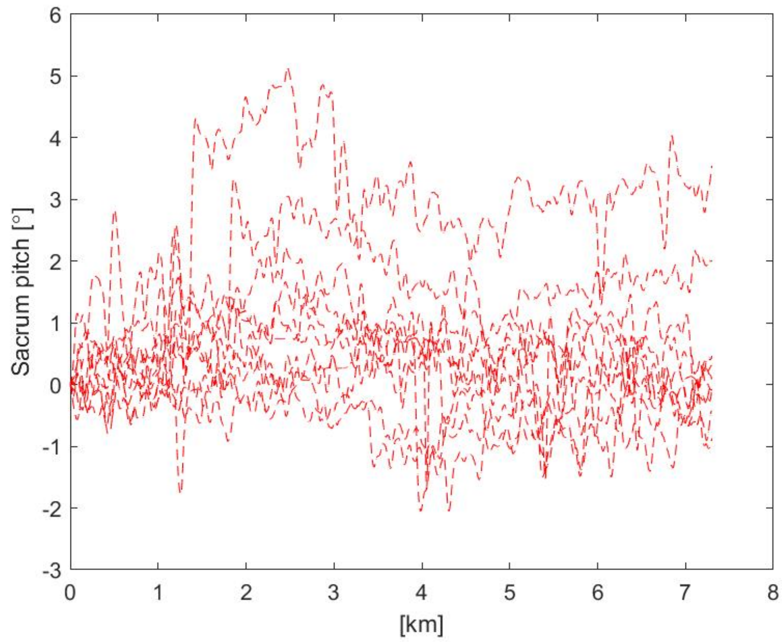

Figure B.35: The Xsens sacrum sensor output for conversing, female.

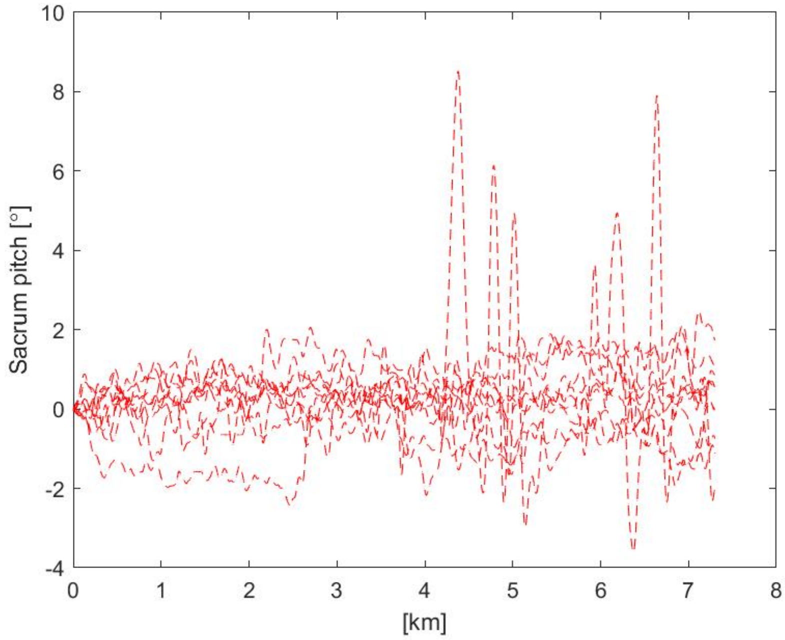

Figure B.36: The Xsens sacrum sensor output for e-socializing, female.

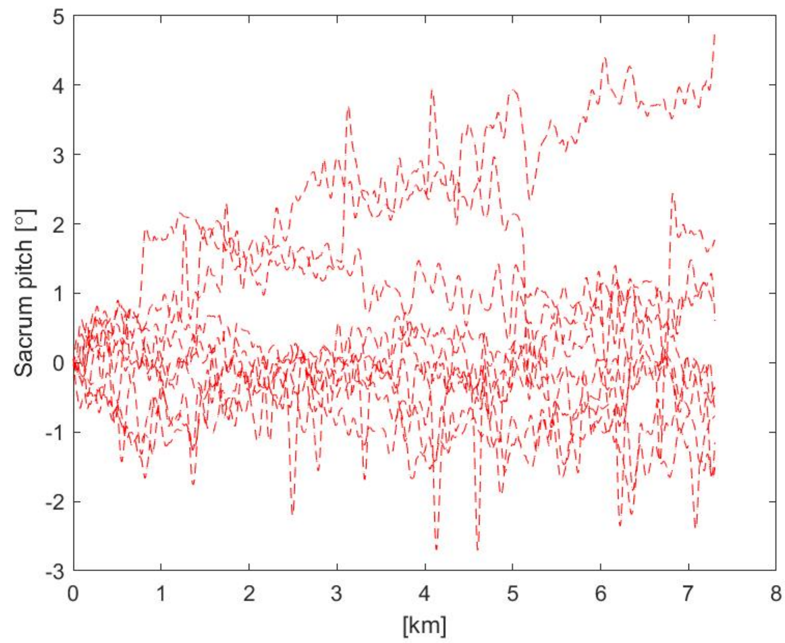

Figure B.37: The Xsens sacrum sensor output for resting, female.

B.4 The lap belt angle in front of iliac wing

In Figures B.38, B.39 and B.40 the lap belt angle in front of iliac wing is shown for the male volunteers. In Figures B.41, B.42 and B.43 the lap belt angle in front of iliac wing is shown for the female volunteers. In Table B.3 the corresponding angles between lap belt angle in front of iliac wing and sacrum pitch. The lap belt angle in front of iliac wing is divided into conversing, Figures B.44, (male B.45 and female B.46), E-socializing, Figure B.47 (male B.48 and female B.49), and resting, Figure B.50 (male B.51 and female B.52).

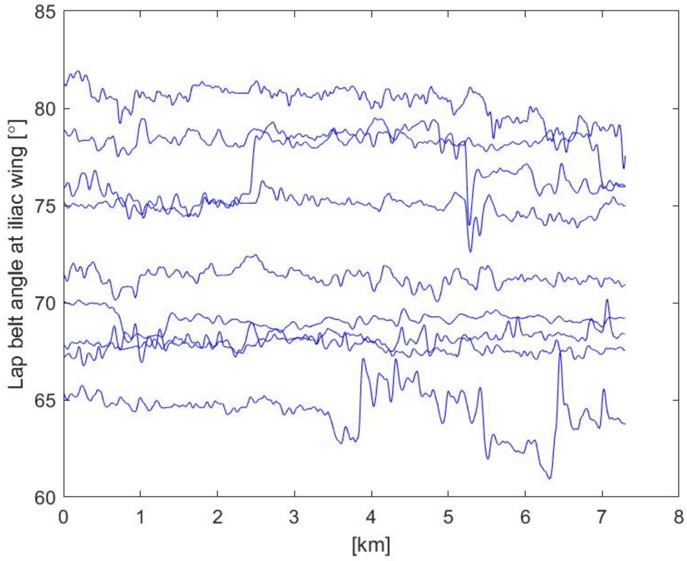

Figure B.38: The lap belt angle in front of iliac wing for loop 1 male.

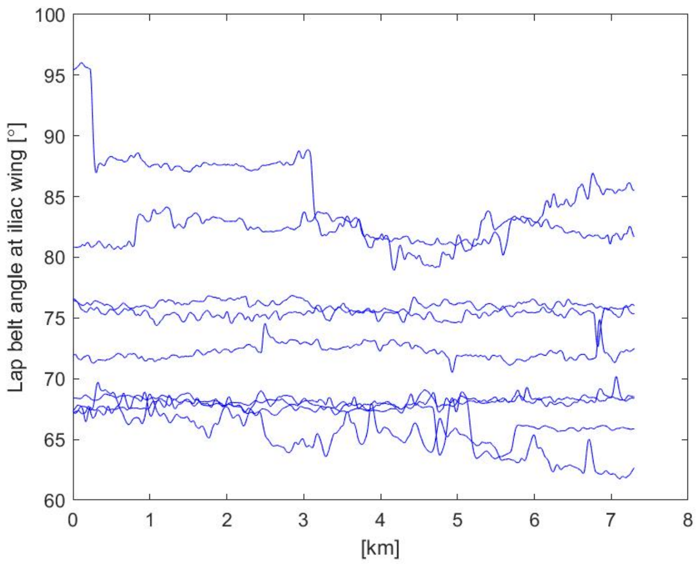

Figure B.39: The lap belt angle in front of iliac wing for loop 2, male.

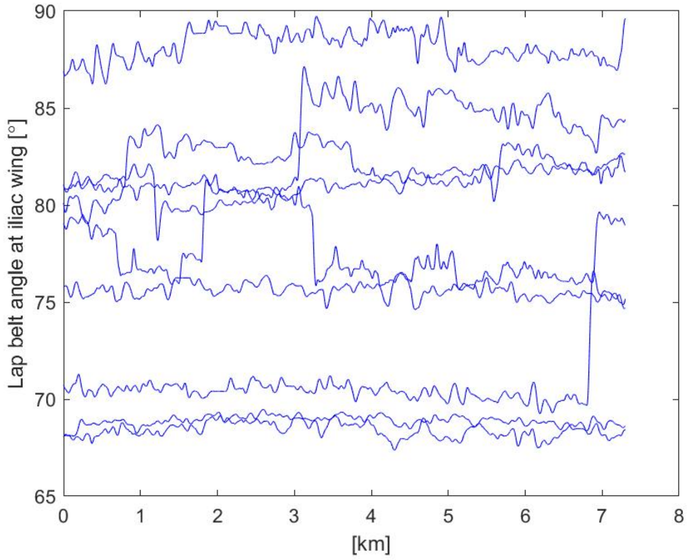

Figure B.40: The lap belt angle in front of iliac wing for loop 3, male.

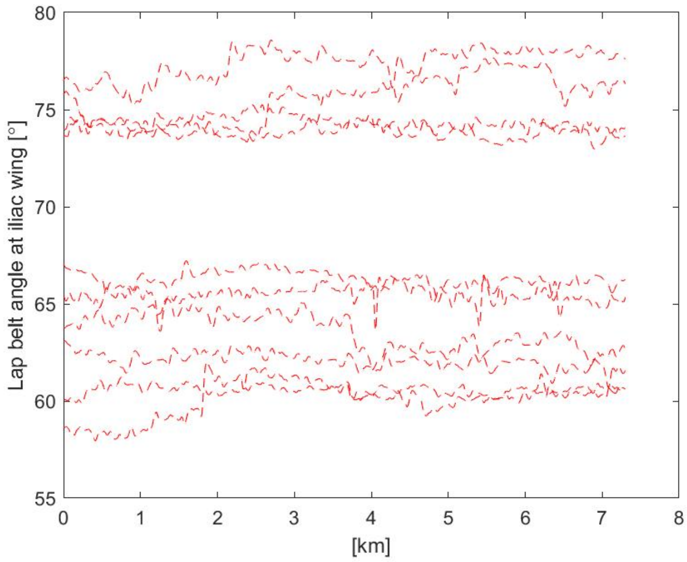

Figure B.41: The lap belt angle in front of iliac wing for loop 1, female.

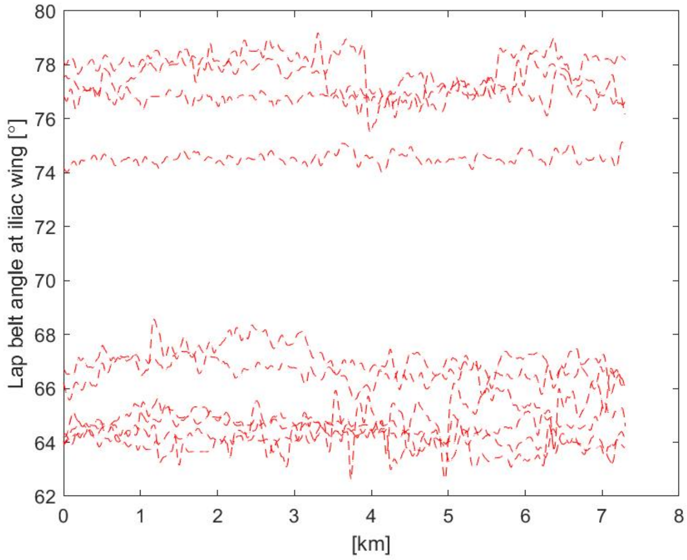

Figure B.42: The lap belt angle in front of iliac wing for loop 2, female.

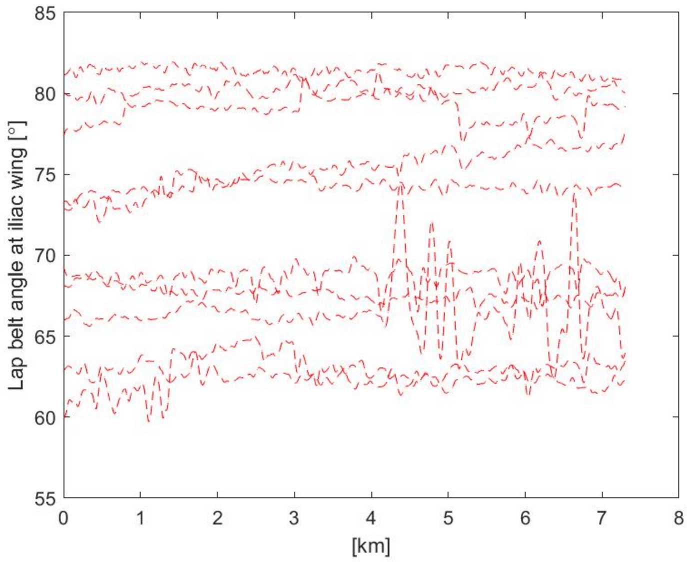

Figure B.43: The lap belt angle in front of iliac wing for loop 3, female.

Volunteer	Sacrum pitch	Lap belt angle in front of iliac wing
Volunteer 1 (m)	27.2°	79°
Volunteer 2 (m)	27.0°	67°
Volunteer 3 (m)	22.3°	69°
Volunteer 4 (f)	32.2°	64°
Volunteer 5 (f)	31.2°	61°
Volunteer 6 (m)	27.5°	68°
Volunteer 7 (f)	34.6°	70°
Volunteer 8 (m)	30.8°	64°
Volunteer 9 (f)	25.5°	70°
Volunteer 10 (f)	15.2°	62°
Volunteer 11 (f)	17.2°	73°
Volunteer 12 (f)	26.7°	57°
Volunteer 13 (f)	32.7°	70°
Volunteer 14 (m)	27.3°	65°
Volunteer 15 (f)	25.5°	64°
Volunteer 16 (m)	29.8°	73°
Volunteer 18 (m)	29.9°	69°
Volunteer 19 (m)	24.5°	74°
Volunteer 20 (f)	25.6°	69°

Table B.3: Sacrum pitch when lap belt angle in front of iliac wing is measured, where (m) represents male and (f) represents female.

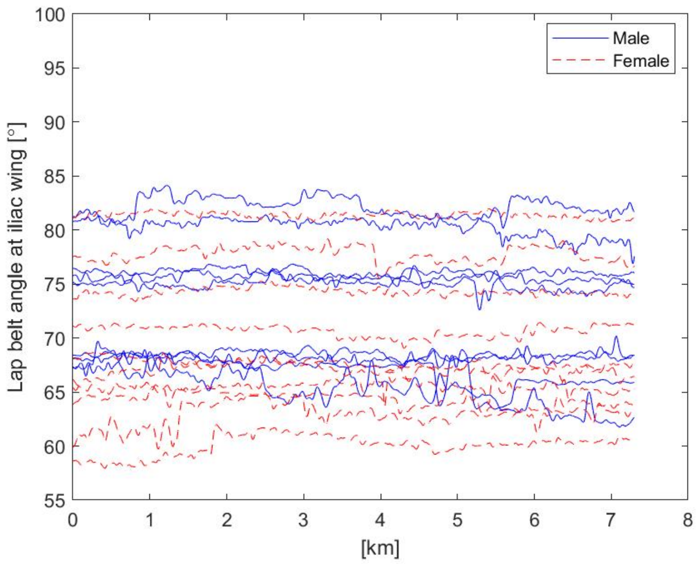

Figure B.44: The lap belt angle in front of iliac wing for conversing.

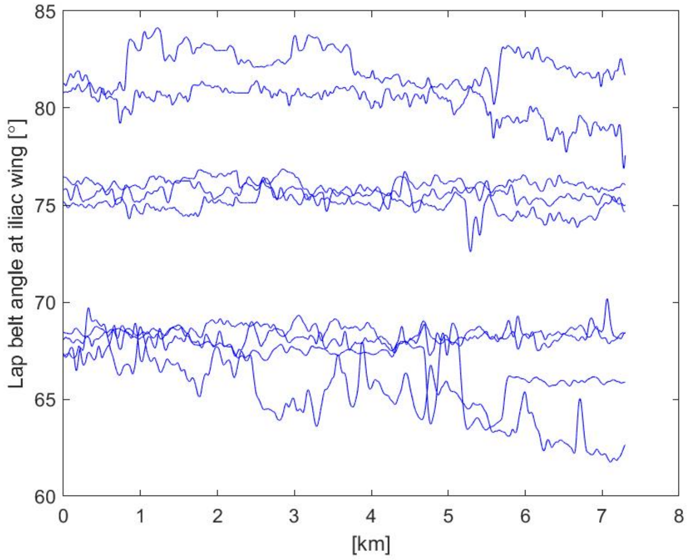

Figure B.45: The lap belt angle in front of iliac wing for conversing, male.

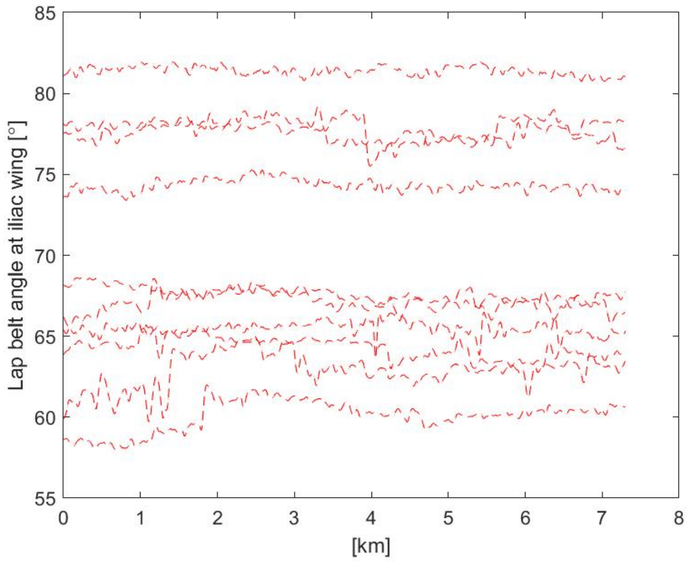

Figure B.46: The lap belt angle in front of iliac wing for conversing, female.

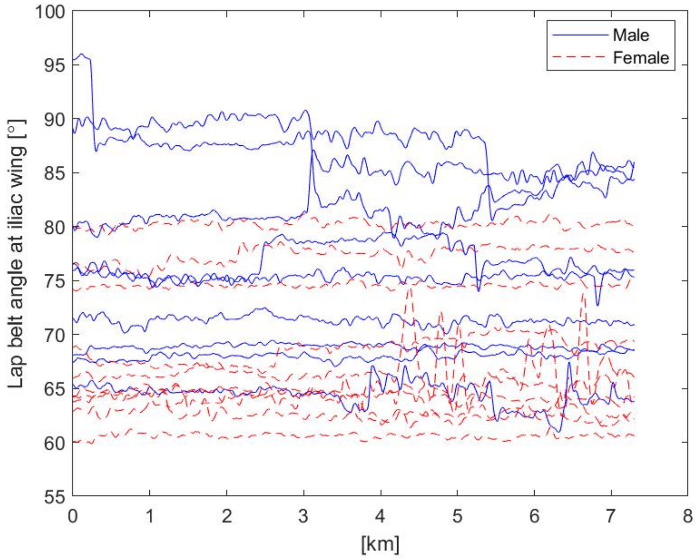

Figure B.47: The lap belt angle in front of iliac wing for E-socializing.

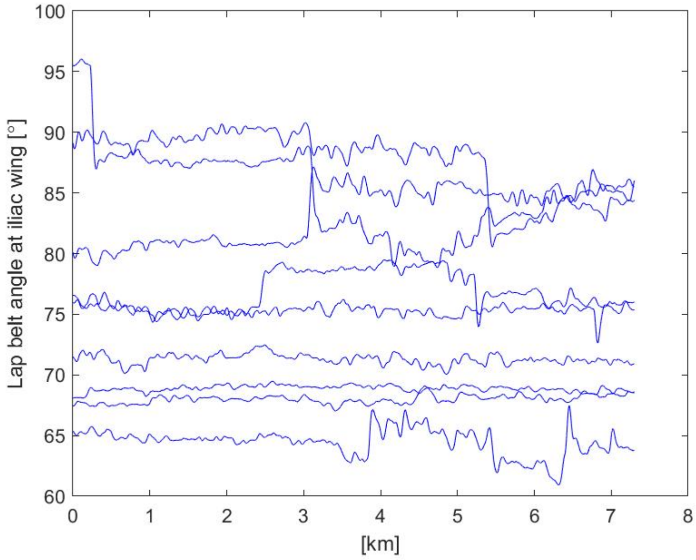

Figure B.48: The lap belt angle in front of iliac wing for E-socializing, male.

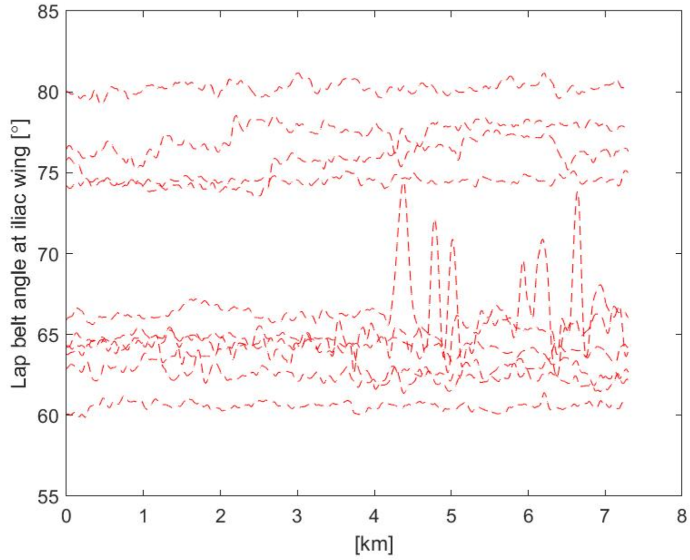

Figure B.49: The lap belt angle in front of iliac wing for E-socializing, female.

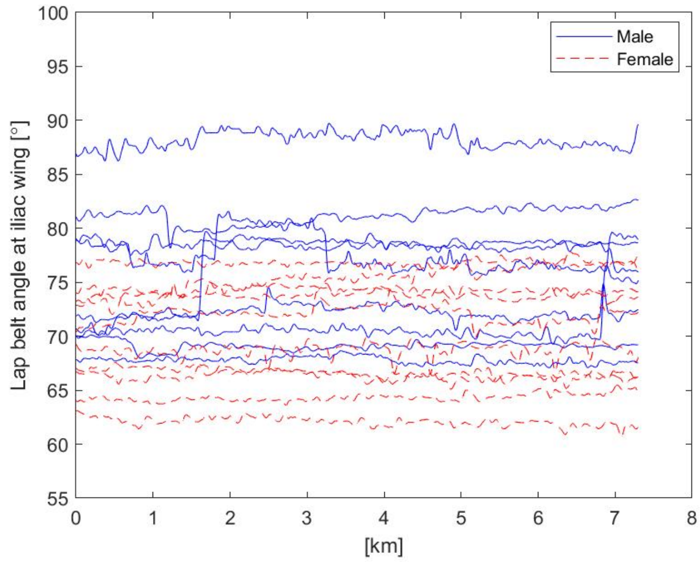

Figure B.50: The lap belt angle in front of iliac wing for resting.

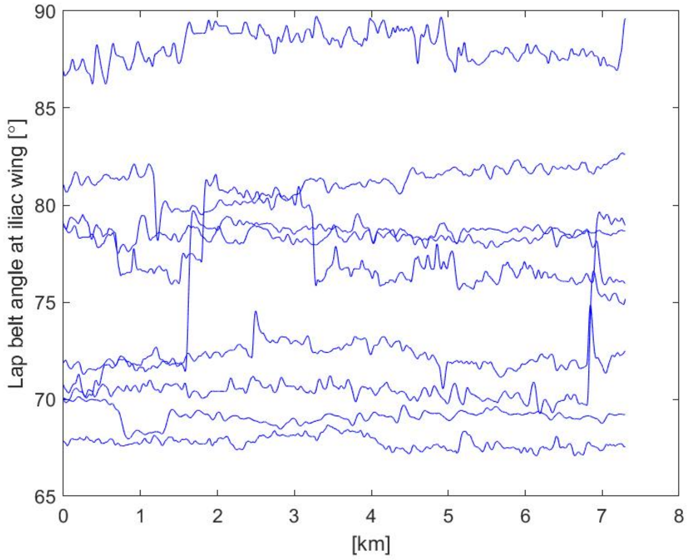

Figure B.51: The lap belt angle in front of iliac wing for resting, male.

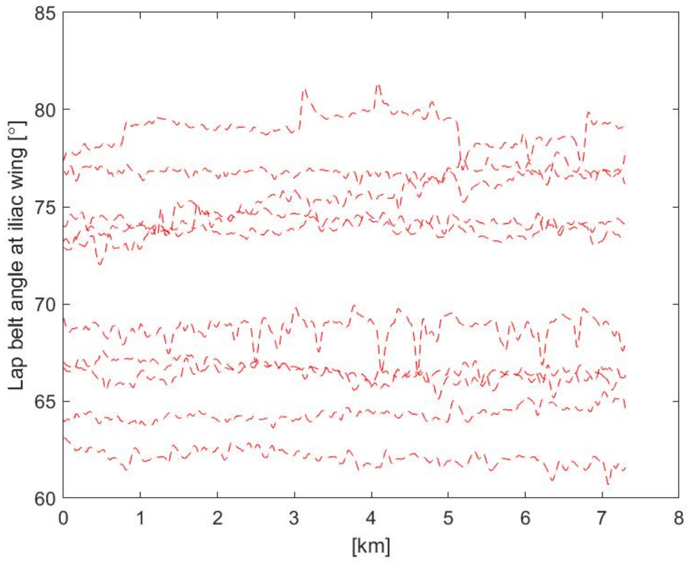

Figure B.52: The lap belt angle in front of iliac wing for resting, female.

B.5 Variation of seat back angle

In Table B.4 the sacrum pitch when changing seat back angle is shown and in B.5 the sternum pitch is presented.

Volunteer	23°	28°	33°	38°	43°	48°
Volunteer 1	26.5°	30.4°	33.3°	35.4°	38.5°	41.3°
Volunteer 2	29.6°	32.7°	32.6°	35.1°	38.7°	40.8°
Volunteer 3	21.5°	27.5°	32.1°	31.5°	34.9°	39.6°
Volunteer 4	31.1°	34.0°	38.0°	41.7°	45.0°	46.0°
Volunteer 5	27.3°	29.8°	31.0°	36.5°	37.8°	42.0°
Volunteer 6	25.0°	28.9°	32.7°	33.8°	x39.0°	39.5°
Volunteer 7	33.4°	35.6°	40.5°	40.4°	42.3°	47.5°
Volunteer 8	34.5°	36.6°	41.2°	39.5°	46.9°	48.5°
Volunteer 9	23.9°	28.3°	30.9°	34.9°	39.2°	40.9°
Volunteer 10	16.3°	21.5°	25.6°	29.9°	31.9°	35.1°
Volunteer 11	13.5°	20.1°	25.6°	27.8°	35.3°	38.2°
Volunteer 12	31.1°	38.1°	41.7°	42.0°	45.6°	48.9°
Volunteer 13	28.2°	32.0°	35.6°	38.2°	41.5°	44.3°
Volunteer 14	31.1°	32.4°	33.0°	34.1°	38.1°	42.8°
Volunteer 15	28.6°	32.5°	37.4°	42.8°	46.7°	49.6°
Volunteer 16	28.4°	27.3°	28.6°	31.3°	40.6°	37.6°
Volunteer 18	27.8°	30.7°	35.0°	40.3°	46.0°	48.4°
Volunteer 19	23.6°	25.8°	27.6°	31.4°	32.9°	34.2°
Volunteer 20	29.1°	36.4°	41.3°	43.0°	46.8°	49.8°

Table B.4: Changing seat back angles; 23°, 28°, 33°, 38°, 43°, 48°. The sacrum angles are listed.

Volunteer	23°	28°	33°	38°	43°	48°
Volunteer 1	40.8°	48.3°	56.7°	59.7°	68.1°	73.8°
Volunteer 2	31.9°	36.8°	42.3°	50.0°	55.4°	58.6°
Volunteer 3	30.3°	35.3°	41.6°	48.8°	57.7°	67.3°
Volunteer 4	45.1°	53.8°	60.4°	67.2°	72.6°	78.8°
Volunteer 5	29.4°	36.7°	43.1°	49.7°	54.0°	62.1°
Volunteer 6	45.1°	51.5°	59.7°	66.8°	71.5°	77.2°
Volunteer 7	33.2°	49.0°	53.5°	57.9°	62.3°	69.8°
Volunteer 8	38.2°	45.6°	57.4°	56.9°	62.7°	69.1°
Volunteer 9	33.2°	40.5°	45.4°	51.1°	57.5°	64.4°
Volunteer 10	37.5°	44.0°	50.3°	54.7°	61.2°	70.3°
Volunteer 11	41.4°	47.4°	52.6°	59.8°	63.8°	73.0°
Volunteer 12	15.1°	26.5°	35.8°	43.7°	48.6°	53.9°
Volunteer 13	40.0°	51.3°	54.8°	60.0°	65.5°	70.5°
Volunteer 14	46.4°	53.4°	58.3°	63.3°	71.4°	79.0°
Volunteer 15	38.5°	46.3°	53.4°	59.0°	66.9°	72.2°
Volunteer 16	29.8°	39.4°	45.4°	49.1°	59.1°	64.2°
Volunteer 18	23.5°	26.3°	34.1°	41.1°	51.9°	62.1°
Volunteer 19	35.1°	42.8°	48.3°	54.8°	61.2°	68.0°
Volunteer 20	27.6°	32.5°	39.5°	45.2°	50.8°	60.3°

Table B.5: Changing seat back angles; 23°, 28°, 33°, 38°, 43°, 48°. The sternum angles are listed.